Selective drug effects on information processing

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SELECTIVE DRUG EFFECTS

ON INFORMATION PROCESSING

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SELECTIVE DRUG EFFECTS ON INFORMATION PROCESSING

PROMOTOR: PROF. DR. A.F. SANDERS

SELECTIVE DRUG EFFECTS ON INFORMATION PROCESSING

Proefschrift

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Voor mijn moeder

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PREFACE

The origins of this research go back to 1971 when Sanders and Bunt published a literature review about the effects of drugs on human performance. On the basis of their reading, they suggested that some tasks seem to be more sensitive to drug effects than others, and they suggested that future research should be directed at determining the critical task parameters of a drug effect. This suggestion was put into practice when a few years later, the Institute of Perception received a financial grant to carry out research on the subject "brain and behaviour". During this time, the late Don Trumbo was working at the Institute and contributed in an important way to setting up this research. A stimulant and a depressant were selected in consultation with a group of pharmacologists, and two exploratory studies were carried out with reaction time tasks (Trumbo and Gaillard, 1975) and a tracking task (Truijens, Trumbo and Wagenaar, 1976) as paradigms. In particular, the Trumbo and Gaillard study suggested a line for further research. Thus a proposal was written by Andries Sanders and Tony Gaillard. It aimed at finding out more about the effects of stimulant and depressant drugs on underlying psychological processes. Its essential features were: firstly, that the research strategy should consist of investigating the effects of the drugs in relation to the effects of certain task variables on performance; secondly, that reaction time tasks should be used as the basic paradigm; and thirdly, that for the purposes of uniformity the same or similar drugs should be used as in the Trumbo and Gaillard study.

In 1975, this proposal resulted in a subsidy from the Foundation for Medical Research FUNGO, and the author was employed to carry out this research, under supervision of Andries Sanders and with the advisory support of Tony Gaillard. After a rather extensive preliminary study (Frowein and Sanders, 1978), a definite line of research evolved. An important influence in this was Sanders' enthusiasm about the additive factor method. Despite some initial reservations about this method, the author became convinced of its utility, not only for identifying processing stages, but also for identifying the effects of drugs or other stresses on these processing stages. The experiments in this thesis fit into this line of research.

The thesis is divided up into two parts. Part I sets out the re-

search strategy, reviews the literature, summarizes the experimental findings, and considers these findings within a broader theoretical framework. Part II consists of a collection of separate research papers which report the experiments in greater detail.

CONTENTS

PART I: REVIEW

CHAPTER 1. RESEARCH STRATEGY

It is generally accepted that depressant drugs such as barbiturates can have a detrimental effect on performance, while stimulants such as amphetamines may help to improve performance. Yet not much is known about the effects of such drugs on the underlying processes which determine task performance. To a certain extent, this is attributable to the applied purpose of many of the studies in this field. Many investigators were primarily interested in finding out whether a certain drug is either harmful or beneficial to performance in specific real-life tasks. Some examples are the investigations by Smith and Beecher (1960) of the effects of amphetamine in different types of athletic tasks, the research on drug effects in simulated air missions (e.g. McKenzie and Elliot, 1965), and the study of marihuana effects on driving performance (Klonoff, 1974). Although these studies can give us a general idea about the type of tasks which are most affected by a drug, they are neither intended nor very suitable to make inferences about the effects of drugs on underlying processes.

More theoretically oriented studies have, until recently, not made much progress either in this respect. In theories of human performance, drugs are usually classified together with variables such as sleep deprivation, noise, and time-of-day, because they are all presumed to affect performance by bringing about some change in the state of the organism. These variables are usually referred to as 'stresses' or 'stressors' (e.g. Broadbent, 1971; Sanders and Bunt, 1971) and their influence on performance has commonly been related to such broad theoretical concepts as arousal, attention and capacity (e.g. Easterbrook, 1959; Berlyne, 1960; Kahneman, 1973), rather than to specific aspects of information processing.

More recently, however, some theorists have come to the conclusion that the organismic changes brought about by different stresses may be quite specific in their effects on information processing (e.g. Broadbent, 1971; Sanders, 1979; Hamilton et al. 1977). This is evident, for instance, from a study by Woodhead (1964) who found that a burst of noise impaired performance in an arithmetic task, but that this effect was dependent upon the relation between the noise and the required operations during differ-

ent parts of the task.

Similarly, the work of Mirsky and Kornetsky (1964) also illustrates this point. They investigated the effects of several barbiturates and a tranquilizer on two different tasks: the Digit Symbol Substitution Test (D.S.S.T.) and the Continuous Performance Test (C.P.T.). In the D.S.S.T., the subject must identify a digit on a test form, obtain the corresponding symbol from a code, and enter this symbol in the proper space beneath the digit. The C.P.T. on the other hand, is a button-pressing task in which the subject is watching letters appearing at fixed intervals on a visual display; his task is to make a response when certain critical letters appear. The results indicated differential drug effects in these two tasks. The barbiturates had a greater effect in the D.S.S.T. than in the C.P.T., while the reverse was true for the tranquilizer. Thus, Mirsky and Kornetsky concluded that barbiturates affect processes which are more important in determining performance in the D.S.S.T., while tranquilizers affect processes which are more important in determining performance in the C.P.T..

However, the next step of identifying these processes is more difficult. The C.P.T. and the D.S.S.T. differ in a number of important respects, such as the mode of stimulus presentation (paced versus self-paced), the type of response and the duration of the task. Since it is likely that these variables may be related to different mediating processes, it remains a matter of speculation which of these processes are responsible for the differential drug effects.

Test battery research

Until recently, many drug studies suffered from such interpretation difficulties. They used a battery of tests to investigate such psychological functions as memory, perception, reasoning ability and motor co-ordination. Apart from the fact that some of these studies also suffer from rather serious methodological flaws, such as always presenting the tests in the same sequence, this approach runs the risk of erroneous interpretations of differential drug effects. When tasks differ in more than one dimension it is never quite clear which dimension is responsible for such a differential effect. It is not surprising therefore that it is difficult to construct a consistent picture on the basis of the experimental literature. For instance, the comprehensive review by Weiss and Laties (1962) of a large number of experiments on the influence of amphetamine and caffeine

on performance is concluded with the remark that:

"Strikingly few attempts have been made to determine the basic parameters of drug action and performance. Such work is essential if we are to develop broad principles." (Weiss and Laties, 1962, p. 32)

A more solid approach to test battery research may have been provided by the research strategy suggested by Fleishman (1967). He proposed that an empirically derived taxonomy of tasks should be developed on the basis of correlational analyses. If individuals who do well on task A also do well on tasks B and C but not on tasks D, E and F, it could be inferred that a common ability determines performance in the first three tasks but has no function in determining performance in the latter three. However, Fleishman's suggested strategy has not been sufficiently followed to provide a generally accepted taxonomy of tasks. And even if it had been, it would not necessarily tell us much about the influence of drugs on the different processes involved in carrying out a task. For instance, it may be that two tasks tax a common ability but differ with respect to the information processing involved in carrying them out; e.g. individuals who are good at an acquisition task may also be good at a memory retrieval task while the two tasks involve different sorts of information processing. Unless such differences in information processing can be specified and independently varied, it is not possible to infer which difference in processing is responsible for a selective drug effect on only one of these two tasks.

Task variables and choice reaction time

To avoid the pitfalls of test battery research, it was suggested by Laties and Weiss (1967) that the aspiring researcher should start by performing a detailed experimental analysis of the behaviour of interest, exploring the potency of parameters that prove important. Only then should he proceed to look at a drug and focus upon the drug's effect on the influence of these parameters.

A similar research strategy was proposed by Sanders and Bunt (1971) and more recently by Gaillard (1979). They recommend that experiments should be carried out which investigate the relationship between the effects of drugs and the effects of certain well-defined task variables. This allows more precise inferences about the critical task variables for particular drug effects. Moreover, if these task variables can be related

to the information processing requirements of the task, it also becomes possible to make specific inferences about the influence of such a drug on information processing.

In this thesis, the research strategy suggested by Sanders and Bunt (1971) was implemented to investigate the effects of a barbiturate and an amphetamine in a series of choice reaction tasks. These tasks are particularly suitable for this purpose. They are perhaps the most investigated type of tasks in human performance research, and the fine-grain measurement of reaction time in milliseconds makes it more likely that drug effects in the relatively small dosages which are commonly used in human drug research will be detected. Moreover, and most importantly, a commonly applied logical framework to make inferences about the effects of drugs on information processing, is provided by the so-called additive factor method. In the following pages, the additive factor method is discussed, firstly as a rationale for constructing a model of information processing, and secondly as a method for interpreting the effects of drugs or other stresses within the context of such a model.

The additive factor method (AFM)

The additive factor method (AFM) was introduced by Sternberg (1969) to provide a research methodology for the discovery of the processing stages which make up reaction time (RT). The basic idea is that these processing stages can be identified by investigating the relationship between different task variables in their effect on RT. This idea can be traced back to the subtraction method of Donders (1868), which, after a long dormant period, was rediscovered as a result of the modern interest in human information processing (e.g. Sanders, 1967; Smith, 1968; Welford, 1968).

The rationale of the AFM is that if two task variables interact in their effects on RT, they are likely to affect at least one common processing stage, since the size of the effect of one variable depends on the level of the other. Alternatively, if two variables have additive main effects on RT, it is inferred that two different processing stages are likely to be involved. A necessary underlying assumption of the AFM is that processing stages are strictly serial, and that their durations are independent. This means that the utility of output of the individual stages must be constant. For instance, although a greater emphasis on

speed versus accuracy could result in incorrect output of a particular stage, the utility of this output for processing in the next stage should remain unaffected.

Although the AFM has provided an important impetus to RT research, some objections to its rationale as well as some practical problems should be recognized. Pachella (1974) and Sanders (1980b) have already discussed most of these points fully, and they are only briefly reviewed here.

A first problem with the AFM is that to accept additivity as evidence implies accepting the null hypothesis. This is particularly troublesome when it is not clear whether one has to do with real additivity or with a non-significant interaction. In such cases it is necessary to defer judgement until further evidence is obtained. Also, in cases where more convincing additive relations are found, the problem of accepting the null hypothesis makes it advisable to be cautious until supporting evidence is found, either from other additive factor experiments or from findings outside the AFM paradigm.

A second problem encountered in the practice of experimentation is that of shifts in the speed-accuracy trade-off. Since AFM research depends only on the measurement of RT's, serious misinterpretations may occur if shifts in the speed-accuracy trade-off are neglected (e.g. Pachella, 1974). In practice, experimenters will usually endeavour to keep error rates low and constant, and it has been suggested by Sanders (1980b) that subjects should be trained in this respect, and that only well-practiced subjects should be used. This may be so, but it limits the scope af AFM research.

Thirdly, there have been attacks on the theoretical assumptions of stage-analysis. It has been argued, for instance, that processing stages may in fact overlap and that increased processing time during one stage may result in decreased processing time in the next stages (e.g. Taylor, 1976; Stanovich and Pachella, 1977). If this point is conceded, it becomes unclear what should be inferred from findings of additivity or interaction. Taylor (1976) emphasizes that additive effects may in fact be disguised overadditive interactions. Stanovich and Pachella (1977) argue that underadditive interactions may be disguised additive effects. Sanders (1980b) has countered these objections by pointing out that a distinction should be made between processes and processing stages. Within a stage, a set of interdependent overlapping processes may occur; but overlap between stages would mean that these sets of processes overlap and should be iden-

tified as a single stage. In other words, processing stages should in the first place be regarded as operational concepts to describe whether or not task variables affect RT via a common mechanism. Although a consideration of task variables may lead to inferences and hypotheses about the nature of the processes within individual stages, these inferences and hypotheses are strictly speaking not part of the AFM rationale.

Nevertheless, it should be recognized that, although Sternberg's model of discrete serial stages may be the most commonly applied model of the reaction process, it is not the only possible model. Several alternative models have been postulated. While some of these (i.e. Theios, 1973; Townsend, 1974) are really alternatives to the hypothesis of Sternberg (1966) of exhaustive memory scanning (which applies to a process within one specific stage rather than to the relationship between stages), there is also a recent paper by McClelland (1979) which postulates the possibility that information processing stages all operate continuously, passing information from one stage to the next as it becomes available. Within this model a task variable could either affect the rate of response within a stage or the asymptotic quality of the output or both of these. This would mean that additive and interactive effects become multi-interpretable. In part, these interpretations are the same as in the discrete stage model. Variables that affect the processing rates of two different stages would have additive effects on RT, whereas variables affecting the rate of the same process would tend to interact. On the other hand, an interaction between two variables could also mean that they both affect asymptotic output whether they affect the same process or not, and additivity could mean that one affects the rate of a fast process and the other affects the asymptote. However, when Sanders et al (1981) applied these alternative explanations to some real data they found them to be highly implausible. In this respect it is good to keep in mind that McClelland postulated the cascade model only as a <u>possible</u> alternative to Sternberg's discrete stage model, and that he never argued that this alternative is more plausible or that the discrete stage model should be abandoned.

It seems therefore that the additive factor analysis of discrete stages can still provide the best possible description of the reaction process. Since its introduction it has generated so much research, that it seemed to some recent writers that half of the cognitive psychologists were devoting themselves to the search for processing stages (Lachman et al. 1979).

A resilient feature of the AFM is undoubtedly that it allows models of stages to be flexibly adjusted to accommodate new findings. On the other hand, it is also conceivable that the AFM would become discredited either because the observed additive and interactive relationships would prove to be unstable or because the pattern of these relationships could no longer be fitted into a plausible model of processing stages. Until now this has not been the case, as is evident for instance from the models by Sanders (1977; 1980a, b). These successive models represent a progressive change from relatively simple to an increasingly complex picture of the reaction process. In principle at least, it should be possible that eventually all the blind spots will be filled in and a final picture of the reaction process will evolve.

Drugs and the additive factor method

In reaction time research a distinction is sometimes made between structural task variables such as stimulus degradation and the compatibility between stimulus and response, and functional variables such as drugs and other stresses. The former are presumed to change the operational requirements of the task while the latter are presumed to change the state of the organism (see Sanders, 1975; and paper 4 in Part II of this thesis). Although the main application of the AFM has been in the discovery of processing stages, and experimenters have usually been concerned with studying the relationship between different structural task variables, the AFM may equally well be applied to the study of functional variables.

Firstly, the AFM may be used to find out which processing stages are affected by a certain drug. If the effect of a drug on RT interacts with the effects of a task variable, it may be inferred that they affect at least one common processing stage. Thus, if that task variable can be linked to one specific processing stage, it may be inferred that the drug affects that particular processing stage. Similarly, if that task variable can be linked to two or more processing stages, it should be inferred that the drug affects at least one but maybe more of these stages. And if the drug and the task variable have additive main effects on RT it should be inferred that they affect different processing stages. Examples of this type of research are the alcohol studies by Huntley (1972, 1974) and Tharp

et al. (1974) which locate the effect of alcohol at a central response selection stage rather than at the earlier stages concerned with perceptual processing or at the later stages concerned with response execution.

Secondly, the AFM may be used to investigate whether two or more drugs or stresses affect a common processing stage. If they interact in their respective effects on RT, it should be inferred that they affect one or more common stages, while additivity would indicate that they affect different processing stages. Within a different context, Broadbent (1971) applied the same type of rationale. He was interested in the effects of different stresses on different types of arousal mechanisms, and argued that if two variables are producing impairment by quite separate mechanisms, each should produce its effect independently of the other, but that they should show an overadditive interaction in their impairment if they affect performance through the same mechanism.

The research in this thesis is primarily an example of the first application of the AFM to drug research. Most of the experiments investigated the influence of amphetamine and a barbiturate on various stages in the reaction process. The two reaction task experiments without drugs (reported in papers 1 and 3A of Part II) merely complement this research. In addition, one of the experiments is also a clear example of the second application of the AFM to drug research. In this experiment (reported in paper 5 of Part II), the joint effects of amphetamine and sleep deprivation were investigated.

CHAPTER 2. TASK VARIABLES AND PROCESSING STAGES

Before starting the discussion about the influence of drugs on processing stages, it is relevant to summarize the existing evidence on processing stages. This chapter discusses the evidence with respect to the stages that can be inferred to make up the reaction process in a standard choice reaction task. This evidence is derived not only from the literature but also from the effects of task variables observed in the research articles in Part II of this thesis. (These research articles will from now on be referred to as paper 1, 2, ... etc.). The aim of this review is to provide an updated integration of the findings, which on the one hand can be used as a framework to locate the effects of the drugs on processing stages, and on the other hand be of some value to other researchers who are interested in the study of processing stages in their own right.

Task variables

When trying to construct a rather detailed model of the processing stages that make up RT in a visual choice task, is is necessary to start with a brief description of the following task variables:

Stimulus variables. These are variables which are presumed to affect the processing of visual stimuli. There are three types of visual stimulus variables. Firstly, visual stimulus intensity, which denotes the luminance of the reaction stimuli. This is sometimes also described as 'stimulus contrast' (Sanders 1980b) because the luminance of the stimuli is usually varied independently of the background luminance. Secondly, visual stimulus degradation, which may be achieved by superimposing for instance a checkerboard pattern (e.g. Sternberg, 1969), a grid of dots (Shwartz et al., 1977) or visual noise (paper 1). The term stimulus degradation has sometimes also inappropriately been used to denote variations in luminance (Stanovich and Pachella, 1977). Thirdly, visual stimulus similarity, which refers to the degree of similarity between the alternative stimuli. Shwartz et al. (1977) employed this independent variable by varying the slope of the upright lines in the capital letters A and H, and Pachella and Fisher (1969) varied the spacing between the possible alternative positions of horizontal bars.

Stimulus-response compatibility refers to the degree of natural asso-

ciation or compatibility between members of the stimulus-response pairs in the choice task. Although S-R compatibility has been varied in many different ways by different experimenters, most of these variations involve either variations in the spatial relationship between stimuli and responses (e.g. Fitts et al., 1963; paper 1), or variations in their semantic relationship (e.g. Sanders, 1970; Shwartz et al., 1977). For each of these categories it has invariably been found that RT's are considerably shorter in the compatible condition than in the incompatible condition.

Relative S-R frequency has also been referred to as relative signal frequency or signal probability. It is varied by varying the relative frequency of occurrence of alternative S-R pairs. For instance, in a four-choice task one of the S-R pairs would occur in 55% of the trials whereas the other three occur only 15% of the time. An increase in relative S-R frequency usually results in shorter RT's (see for instance Sanders, 1970).

Time uncertainty refers to the degree of uncertainty about the moment of presentation of the reaction stimulus. It can be varied in two ways. If the reaction stimulus is preceded by a warning stimulus, time uncertainty is usually varied by varying the foreperiod duration (FPD) between warning stimulus and reaction stimulus; if the FPD is either increased or made more irregular, time uncertainty becomes greater. If there is no warning stimulus, time uncertainty can be increased either by making the inter-stimulus interval longer or by making it more irregular. In both cases, an increase in time uncertainty will bring about an increase in RT (see for instance paper 4).

Accessory refers to an auditory stimulus which is presented simultaneously with the visual reaction stimulus. Although the auditory accessory provides no information value for the selection of the correct response, its presence has been shown to bring about a shortening of RT (e.g. Posner et al. 1976; Sanders, 1980b) and this effect increases as the auditory intensity increases (paper 4).

Response execution variables. These are possible variations in the type of response that the subject has to make. For instance, in paper 3 (experiment 2) a two-choice task adapted from Fitts and Peterson (1964) was used, in which the subject had to move a stylus from a midpoint to either a righthand or a lefthand target. In this type of task it has been usual to vary the amplitude of movement and the width of target, and both

these variables have large effects on the movement time (MT) which is the time necessary to execute the response (e.g. Fitts and Posner, 1967). In addition, their effects on RT may also be studied. Although at least one reviewer (Kerr, 1978) suggested that these two factors fail to influence RT in a consistent fashion, the results reported by Fitts and Peterson (1964) show a small but significant effect on RT while target width had no effect. This is consistent with the results from the experiments in Papers 3 and 5. Also Klapp (1975) and Siegel (1977) carried out similar experiments with a larger range of target widths and movement amplitudes, and for values of width and amplitude similar to those in the experiments in Papers 3 and 5, their data also show longer RT's for longer movements but no mentionable effects of target width. Thus, although the evidence is still somewhat tenuous, it suggests a small effect on RT of movement amplitude but not of target width. For purposes of the stage analysis it is relevant to consider movement amplitude in conjunction with the effects of other task variables. For the same reason, it is worth considering response duration; Spijkers (in preparation) instructed subjects either to make slow (400 msec) or fast (50 msec) motor responses in a left-right choice task, and he found an effect of nearly 60 msec on RT, although subjects were instructed to initiate their responses as fast as possible.

Motor presetting variables. These are several variables that relate to a presetting of the motor response prior to the reaction stimulus. A typical example is muscle tension which was manipulated by Sanders (1980a) by means of instructions, i.e. the instructions were either to optimally tense or to relax the appropriate muscles for initiating a forward pointing movement during the foreperiod preceding the reaction stimulus. Another variable relating to motor presetting is what Sanders (1970) called 'response specificity'. This indicates the extent to which responses have a common element. For instance, in the experiment by Sanders (1970), vocal responses started either with a common or a specific phoneme (e.g. SES or SAS versus ES or AS as responses to E or A). The manipulation of response specificity can also be regarded as a way of varying the 'motor preset compatibility', that is the degree of commonality between the motor presetting for different response alternatives, i.e. when alternative vocal responses start with a common phoneme, motor preset compatibility is high; when they start with different phonemes, motor preset compatibility is low. In pointing responses motor preset compatibility is high if each of the response alternatives involves a forward movement (e.g.

papers 1, 2 and 4), but it is low if the response alternatives constitute a movement to either the right or the left as in the experiment by Fitts and Peterson (1964) and in the experiments in papers 3 and 5.

Processing stages

The additive and interactive relationships among the different task variables are summarized in Tables IA and B, and Fig. 1 pictures a model of stages derived from these results. The arguments for postulating these stages are put forward in the following paragraphs:

Perceptual processing stages. Three processing stages are postulated at the input side of the model. This is consistent with the additive relationships observed between stimulus intensity and degradation (Sanders, 1980b; paper 6), between stimulus intensity and stimulus similarity (e.g. Pachella and Fisher, 1969), and between stimulus degradation and stimulus similarity (Shwartz et al., 1977). The tables also indicate that they are generally found to be additive with task variables which are presumed to affect later stages. The only discordant results in this respect come from some experiments by Pachella and his co-workers. These experiments with digit-naming tasks showed under-additive interactions between visual stimulus intensity and S-R compatibility (Stanovich and Pachella, 1977, experiment 1) and between stimulus intensity and relative S-R frequency (Miller and Pachella, 1973; Stanovich and Pachella, 1977, experiment 1). While Stanovich and Pachella postulate overlapping stages to account for these results, it is noted by Sanders (1980b) that these results may represent a special case because near-threshold stimuli were used in the low intensity conditions. Because of this, a distorted picture may arrive at the response selection stage, and it may be that the more compatible and the more frequent S-R relations would suffer more from this distortion because it would interfere with the natural S-R relationship between the visual digit and the naming of the digit. This could also account for the fact that Stanovich and Pachella (experiments 2 and 3) did find an additive relationship between stimulus intensity and relative S-R frequency when less 'natural' key pressing responses were used instead of naming.

Regarding the nature of the three perceptual processing stages, it may be speculated that stimulus preprocessing represents a peripheral cleaning up of sensory input, that a more central feature analysis occurs during the encoding stage, and that stimulus identificaiton represents the

Table IA. Summary of additive effects of task variables on visual choice reaction time.

Task variables	authors
stimulus intensity + stimulus degradation	- Sanders (1980b) - Paper 7 (this thesis)
stimulus intensity + stimulus similarity	- Pachella and Fisher (1969) - Shwartz et al. (1977)
stimulus degradation + stimulus similarity	- Shwartz et al. (1977)
stimulus intensity + S-R compatibility	- Sanders (1977) - Shwartz et al. (1977)
stimulus intensity + time uncertainty	- Raab et al. (1961) - Sanders (1977) - Niemi (1979)
stimulus intensity + rel. S-R frequency	- Stanovich and Pachella (1977, expts. 2 and 3)
stimulus degradation + S-R compatibility	- Sternberg (1969) - Shwartz et al. (1977) - Sanders (1980a) - Papers 1 and 2 (this thesis)
stimulus degradation + time uncertainty	- Wertheim (1979) - Paper 1 (this thesis)
stimulus degradation + muscle tension	- Sanders (1980a)
stimulus similarity + S-R compatibility	- Pachella and Fischer (1969) - Shwartz et al. (1977)
S-R compatibility + time uncertainty	- Posner et al. (1973) - Sanders (1977) - Paper 1 (this thesis)
S-R compatibility + response specificity	- Sanders (1970)
S-R compatibility + muscle tension	- Sanders (1980a)
rel. S-R frequency + time uncertainty	- Holender and Bertelson (1975)
time uncertainty + accessory	- Sanders (1980b)
time uncertainty + movement amplitude	- Paper 5 (this thesis)
time uncertainty + response duration	- Spijkers (in preparation)
accessory + muscle tension	- Sanders (1980b)

Table IB. Summary of interactive effects of task variables on visual choice reaction time

Task variables	authors
S-R compatibility x rel. S-R frequency	- Fitts et al. (1963) - Broadbent and Gregory (1965) - Sanders (1970) - Theios (1975) - Paper 3 (this thesis)
S-R compatibility x stimulus intensity	- Stanovich and Pachella (1977, expt. 1)
rel. S-R frequency x stimulus intensity	- Miller and Pachella (1973) - Stanovich and Pachella (1977)
rel. S-R frequency x time uncertainty	- Bertelson and Barzeele (1965)
rel. S-R frequency x muscle tension	- Sanders (1980a)
rel. S-R frequency x response specificity	- Sanders (1970)
time uncertainty x muscle tension	- Sanders (1980a, expt. 1)
time uncertainty x accessory	- Paper 4 (this thesis)
time uncert. x rel. S-R freq. x muscle tens.	- Sanders (1980a, expt. 2)

final selection from a set of possible stimulus alternatives. It should be noted, however, that the evidence to support three independent processing stages is still quite meagre. This applies particularly to the postulated stimulus identification stage, and more work will need to be done to confirm the additive relation of stimulus similarity with stimulus degradation, and to investigate the relationship of stimulus similarity with relative S-R frequency and other task variables which are presumed to affect the later processing stages.

Response selection. With the exception of the aforementioned interaction between S-R compatibility and visual stimulus intensity, which in the discussion on perceptual stages was argued to represent a special case, it appears that the effect of S-R compatibility is additive with the effects of the other task variables associated with the perceptual processing stages. Additivity between the effects of S-R compatibility and stimulus intensity is the more common finding (Sanders, 1977; Shwartz et al., 1977); it is well-established that the effect of S-R compatibility

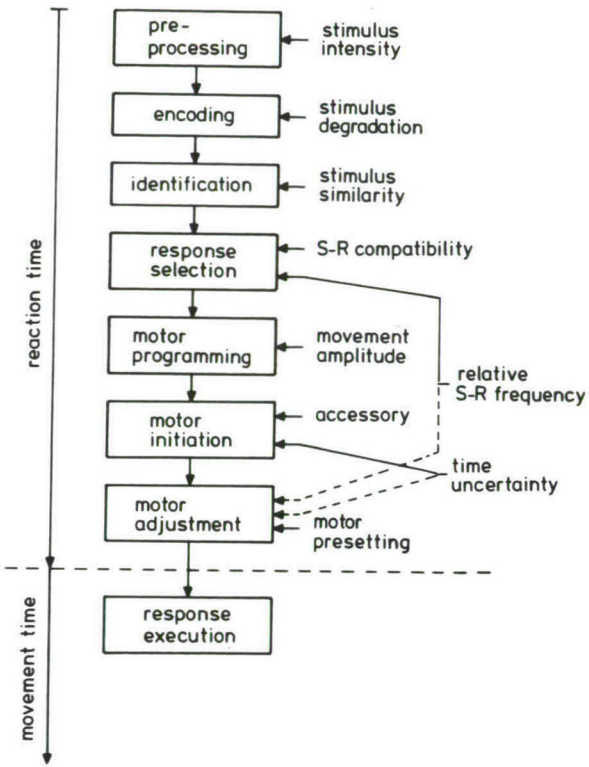

Fig. 1. Task variables and inferred stages in the reaction process.

is additive with the effect of stimulus degradation (Sternberg, 1969; Shwartz et al., 1977; Sanders, 1980a; Papers 1 and 2), and the relationship between the effects of S-R compatibility and stimulus similarity has also been shown to be additive (Fisher and Pachella, 1969; Shwartz et al., 1977). Furthermore, the effect of S-R compatibility has also been shown to be additive with the effects of such variables as time uncertainty (Posner et al., 1973; Sanders, 1977; Paper 1), and muscle tension (Sanders, 1980a), which are presumed to affect stages further on the output side of the reaction process. Consistent with this, it is generally inferred that S-R compatibility affects a stage between perception and output. This may be referred to as 'response selection' or 'response choice'. The only other variable which shows a consistent and strong interaction with S-R compatibility is relative S-R frequency. Some findings even suggest that the effect of relative S-R frequency may disappear altogether in a highly compatible task (Theios, 1975) although most investigators have found that rather small but stable effects remain in their most compatible condition (Fitts et al., 1963; Broadbent and Gregory, 1965; Sanders, 1970; Paper 3). In any case, it is fairly well-established that relative S-R frequency has an important effect on response selection. Other interactions involving relative S-R frequency were reported by Sanders (1980a). He found a first-order interaction between the effects of relative S-R frequency and muscle tension and a second-order interaction between the effects of relative S-R frequency, muscle tension and time uncertainty. In addition, there are some inconsistent findings with respect to the relation between relative S-R frequency and time uncertainty. Bertelson and Barzeele (1965) reported an interaction, but in a follow-up experiment by Holender and Bertelson (1975) it was found that relative S-R frequency was additive with time uncertainty.

Motor programming. The evidence regarding an independent motor programming stage is not yet well-established. The idea that a motor response may be programmed prior to initiation was initially supported by the finding that responses which last shorter than about 220-290 msec are 'ballistic' in the sense that they cannot be corrected on the basis of visual feedback (e.g. Klapp, 1975). In recent years, there has been much interest in investigating the effect on RT of certain variations in arm and hand movements. The most frequently tested are movement amplitude and target width, which are usually manipulated in a Fitts and Peterson task (e.g. Paper 3, Experiment 2). As already mentioned, it appears that move-

ment amplitude may have a small but consistent effect on RT, while target width appears to have no mentionable effect. On the other hand, it is now fairly well-established that larger effects on RT can be achieved by varying such factors as the number of sequential response units (MacKenzie and Roy, 1978; Sternberg et al., 1978), the timing within a response (Jagacinski et al., 1978; Rosenbaum, 1980) and the response duration (Klapp and Erwin, 1976; Spijkers, in preparation).

Also, it appears that motor programming does not constitute a set of detailed instructions to specific muscles (Klapp, 1977). The picture that emerges from recent theories such as proposed by Sternberg et al. (1978) and Marteniuk and MacKenzie (1980) is that motor programs specify such global response aspects as the direction of the response, the sequencing and phasing of the response units and the force-time requirements; and that they include instructions for sensing and responding to feedback during the execution phase.

It is not clear how motor programming fits into the sequence of stages, because very little work has been done to investigate the relationship between the respective effects on RT of the different task variables which are presumed to affect motor programming and task variables which are presumed to affect other stages. In the model proposed in Fig. 1 only one motor programming stage is proposed, but it could be that there are more. For instance, Sternberg et al. (1978) postulated two motor programming stages followed by a command stage. The two task variables associated with motor programming in Fig. 1 are mentioned not because they are the only ones associated with motor programming, but because their effects on RT in a choice reaction task have been investigated in conjunction with other task variables. In particular,there is some evidence that the effect of time uncertainty is additive with the effects of movement amplitude (Paper 5) as well as response duration (Spijkers, in preparation). Furthermore, Sternberg et al. (1980) found that in a simple naming task the effect of time uncertainty on RT was additive with the effects of word length (one versus two syllables) as well as with the number of response units (number of words). Thus, one of the few tentative inferences that can be made is that variables which are usually associated with motor programming do not affect a common stage with time uncertainty.

Motor initiation and motor adjustment. The evidence suggests that time uncertainty affects none of the stages discussed so far. It has been shown that its effect is additive with the effects of visual stimulus intensity (Raab et al., 1961; Sanders, 1977; Niemi, 1979), stimulus degradation

(Paper 1; Wertheim, 1979) and S-R compatibility (Posner et al., 1973; Sanders, 1977; Frowein and Sanders, 1978a). Thus, although the relationship between time uncertainty and stimulus similarity still needs to be investigated, it seems a fair guess that time uncertainty has no effect either on the perceptual stages or on response selection. Also, time uncertainty appears to have no effect on the motor programming stage; because choice reaction experiments have indicated its effect to be additive with the effects of response execution variables such as movement amplitude (Paper 5) and response duration (Spijkers, in preparation), and the naming experiments by Sternberg et al. (1980), showed that the effect of time uncertainty on simple RT was unaffected by the effects of both the length and the number of words that had to be pronounced.

Thus, by a process of elimination it would seem that time uncertainty affects only a later stage or stages of processing. This is consistent with the hypothesis that time uncertainty affects the level of motor preparation, which is the subject's preparatory state with respect to motor response (e.g. Gottsdanker, 1975; Sanders, 1977). Although it has also been argued that time uncertainty affects the perceptual or central decisional level (Klein and Kerr, 1974; Laming, 1968), there is some psychophysiological as well as behavioural evidence to support the motor preparation hypothesis. In particular it has been shown that the amplitude of the so-called 'terminal CNV' in EEG recordings (i.e. a slow negative shift preceding the presentation of reaction stimulus), which can be regarded as the cortical correlate of motor preparation (Rohrbaugh et al., 1976; Gaillard, 1980), is selectively affected by time uncertainty, in the sense that the amplitude of terminal CNV increases with reduced time uncertainty (Loveless and Sanford, 1974) while it is unaffected by stimulus degradation (Gaillard, 1978). Furthermore, at the behavioural level, Sanders (1980a) found that presetting a motor response by instructed muscle tension during the foreperiod served to decrease choice RT by some 40-60 msec; and this effect interacted with the effects of time uncertainty while it was additive with the effects of stimulus degradation and S-R compatibility (Sanders, 1980a).

Regarding the nature of motor preparation, two aspects of this process are postulated. It is postulated, firstly, that the subject's readiness to initiate a respond will increase during motor preparation and secondly, that subjects will already perform in advance that part of the response which can be performed in advance (e.g. Näätänen and Merisalo, 1977). In

the model these two aspects of motor preparation which may be referred to as response readiness and motor presetting relate to separate stages, i.e. motor initiation and motor adjustment respectively. Following the additive factor method, the postulation of these two stages instead of the one motor adjustment stage postulated by Sanders (1980a, b) is supported by the pattern of relationships between the effects of an auditory accessory, time uncertainty and muscle tension in their respective effects on RT.

Firstly, it has been observed that the effect of an auditory accessory interacts with the effect of time uncertainty (Paper 4; Sanders, 1980b, Table 6), and it may thus be inferred that they are likely to affect a common processing stage. To discover the nature of this stage, it is relevant to consider the nature of the accessory effect. Following the literature it may be postulated that auditory stimuli of sufficient loudness may bring about a sudden change in the state of the organism which may be referred to as 'immediate arousal' (Bertelson and Tisseyre, 1969; Sanders and Wertheim, 1973). Similarly, Posner et al. (1976) propose that auditory as opposed to visual stimuli have an automatic alerting effect. Given the immediate arousing effect of the accessory and the interaction of this effect with the effect of time uncertainty, it is postulated that immediate arousal increases the subject's readiness to respond. To put it more formally, immediate arousal may be regarded as a very fast change in the state of the organism and one (or perhaps the only one) characteristic of this change would be an increased readiness to respond. This hypothesis accords well with the theoretical analysis by Nickerson (1973) who proposed that an auditory accessory will modify the preparatory state of the organism.

Within the context of stage analysis, this change in 'readiness to respond' is postulated to affect a stage denoted as 'motor initiation' to suggest that during this time the appropriate go-signals are given to initiate motor execution. This may perhaps be analogous to the 'command' stage postulated by Sternberg et al (1978). Also, following Näätänen and Merisalo (1977), this stage may be regarded as the process of transgressing the 'motor action limit', which reflects the level of response readiness at which it will 'automatically flow over' into response execution. Thus, manipulations such as the reduction of time uncertainty and the presentation of an auditory accessory stimulus would reduce the time spent during motor initiation by decreasing its distance from the motor

action limit. Similarly, it may be suggested that the level of response readiness will be affected by instructions that stress speed versus accuracy or vice versa. This suggestion can be related to the finding by Gaillard and Perdok (1980) that the amplitude of the terminal CNV is greater when instructions stress speed rather than accuracy. It has already been mentioned that the late terminal CNV may be regarded as a psychophysiological correlate of motor preparation. To adapt this relationship more precisely to the present model it may be postulated that the terminal CNV reflects the level of response readiness rather than the motor presetting aspects of motor preparation, and that the greater the amplitude of the terminal CNV, the less time will be spend during the motor initiation stage. This is also consistent with a recent study by Gaillard et al. (1980) in which it was shown that the amplitude of the terminal CNV was unaffected by motor presetting through instructed muscle tension.

The postulation of the motor adjustment stage as separate from motor initiation, is consistent with the finding by Sanders (1980b) that in a choice reaction task, the effect of a motor presetting variable such as muscle tension, is additive with the accessory effect. Although the same study also showed an interaction between these two task variables in a selective reaction task, the error rates reported for this experiment suggest that this may again be attributed to systematic variation in the speed-accuracy trade-off. If the speed-accuracy trade-off had been held constant (as appears to have been the case in the choice task), the effects of accessory and muscle tension may also have had additive effects in the selective task (see Sanders, 1980b, Table 7).

Regarding the nature of motor adjustment, it is postulated that this stage constitutes the first part of response execution, i.e. the muscular processes occurring during RT which are necessary to initiate a response. Three other factors are postulated to affect the extent of motor presetting, and hence the duration of the motor adjustment stage. First, more presetting may occur if the response alternatives have high motor preset compatibility; for instance through a common vector in case of pointing movements or a common phoneme in case of vocal responses (as suggested before, the manipulation of 'response specificity' may be regarded as an example of varying the motor preset compatibility). Second, in case of low motor preset compatibility between the alternative responses, the subject may prepare for the most likely alternative; thus if relative

S-R frequency is varied, motor presetting will be greater for the most frequent response. Third, time uncertainty is postulated to affect motor presetting because it is presumed to be more difficult to maintain an optimal level of motor presetting over a period of time (Gottsdanker, 1975).

Movement time

In several of the experiments in Part II, the experimental task allowed the measurement of MT, which was treated as an index of the duration of response execution. Because it is usually found that task variables with large effects on RT have only a small or no effect on MT (Fitts et al., 1963; Papers 1, 2, 4 and 5), it was further postulated that response execution represents a process which is largely independent of the preceding stages which make up RT. The only exception is the motor adjustment stage which, as argued in the previous section, may be regarded as the first part of response execution.

With respect to independent variables such as movement amplitude and target width which have been shown to have large effects on MT, the logic of the AFM could in principle be applied (see for instance Sternberg et al., 1978). Thus, if two task variables have additive effects on MT, it may be suggested that they affect different stages in MT. Inferences of this nature were for instance suggested in Paper 3. However, it is clear that a stage analysis of MT would have to be based on more elaborate research, clearly beyond the scope of this thesis.

What makes MT interesting from the point of view of the aims of this research, is that it allows inferences about the effects of a drug or other stress on the motor output of the reaction process. Whether or not MT may be regarded as purely a motor output process, depends in the first place on the duration of MT. When MT is shorter than about 200 msec (as was the case in the experiments described in Papers 1, 2 and 4), response execution may be regarded as a purely ballistic motor process, because there is not enough time for visual feedback to play a role, and other forms of feedback are not sufficient for motor control (e.g. Klapp, 1975). For longer MT's (as in the experiments described in Papers 3 and 5), visual feedback and decisional processes as well as motor output processes may play a role in determining MT.

CHAPTER 3. BACKGROUND INFORMATION ABOUT THE DRUGS

Selection of the drugs

As noted in the preface, the drugs were selected in consultation with pharmacologists. A first consideration in this selection was that a stimulant and a depressant compound should be used. A second consideration was that subjects would have to be tested for a period of about 4 to 5 hours, during which they had to carry out different types of experimental tasks. Thus, the concentration of the drug in the body should be reasonably constant during this period. And a third consideration was that the drugs should still be clinically used, so that the possibility of applied relevance should not be excluded.

Given these preconditions, the compound phentermine HCl was selected as the stimulant drug and the compound pentobarbital Na was selected as the depressant drug. The administration mode of these drugs was by suppository because this would ensure a stable plasma concentration during experimental tests (Breimer, 1974; Vree, 1973).

The compound phentermine HCl belongs to the class of amphetamine derivatives which were most commonly used as diet pills, although it has been pointed out that their appetite depressant effect is inseparable from their stimulant effect (e.g. Van Praag, 1966; Nickerson, 1975). The dosage used was 20 or 40 mg. The smaller of these two dosages is about equal to the dosage which is taken three times daily to suppress the appetite. Of course, for the present study only the stimulant effects of phentermine are of interest. In the research reports of this thesis, and in the discussion of the experimental findings in the following chapters, the general term amphetamine is usually used instead of the more specific term phentermine. However, it should be realized that there may de differences in the biochemical and behavioural effects of phentermine as compared to the other amphetamines such as dextro-amphetamine and methamphetamine, which are commonly used in the other studies on the effects of amphetamine on human performance. In the following pages this point will be returned to more specifically.

The compound pentobarbital Na is used as either a sedative or as a hypnotic. The dosage of 100 mg that was used, may be expected to have a mild sedative effect in non-fatigued subjects during the day. Administration of both types of drug as well as a placebo was rectal. This

method of administration was chosen to ensure a constant plasma-level over a period of about 5 hours, starting at about 1 hour post-drug. The experimental tasks were always carried out during this period.

On the nature of amphetamines

The term amphetamine refers to amphetamine and the various amphetamine derivatives, one of which is phentermine. They are usually classified as psychostimulants. At low to moderate dosages, the subjective effects of amphetamines, if any, are mostly those of increased alertness and energy. It is also well-established that amphetamines are particularly effective in counter-acting fatigue and sleepiness. On the other hand, there is also some evidence of 'paradoxically calming' effects of amphetamines. Tecce and Cole (1974), who used normal adults as subjects, observed that two-thirds of their subjects displayed signs of drowsiness at about 30-50 minutes after amphetamine usage, although increased alertness was again observed at 1-2 hours post-drug.

Clinical usage. This 'calming' effect of amphetamines has been clinically used to reduce restless-impulsive behaviour in so-called 'hyper-active children, and similar effects have also been observed with normal children (Rapoport et al., 1978). Amphetamines have also been used to prevent attacks of sleep in narcoleptic patients and to alleviate the symptoms of Parkinson's disease, where it decreases motor rigidity in many patients (Innes and Nickerson, 1975). But the most common clinical usage of amphetamines is as appetite depressants in the treatment of obesity. As mentioned before, the compound phentermine hydro-chloride which is used in the experiments of this thesis, has been prescribed for this purpose.

Biochemical effects. Amphetamines belong to a class of compounds which act on catecholaminic synapses. The current view is that they cause the release of both norepinephrine and dopamine, at the presynaptic terminal. In addition, amphetamines block the re-uptake of these transmitter substances and hence interfere with their inactivation. The effects of amphetamine on these two neurotransmitters appear to mediate different effects. The effect on dopamine appears to mediate the alleviation of Parkinsonism and the stereotypic behaviour which has been observed after amphetamine usage. It has therefore been suggested that dopamine

plays a role in motor control (Papeschi, 1972; Iverson and Iverson, 1975).

Regarding the effect of amphetamine on norepinephrine, it is generally accepted that the release of norepinephrine onto the receptive surfaces of the sympathetic neurons is responsible for their effects on the sympathetic nervous system (e.g. Levitt and Lonowski, 1974). For this reason, amphetamines are also categorized as belonging to the general group of sympathetic amines, affecting both alpha and beta receptors (Kornetsky, 1969). When the sympathetic nervous system is activated, one can generally observe dilation of the pupils, rise in blood pressure and increased frequency and variability of heart rate. The evidence also suggests that the release of norepinephrine is responsible for the effect of amphetamine on increased behavioural activity such as can be observed in animal experiments (e.g. Kornetsky, 1976). In particular, a study by Taylor and Snyder (1971) indicates that the effect of amphetamine on exploratory motor behaviour in rats is mediated by the action of norepinephrine. They showed that dextro-amphetamine is ten times more potent than levo-amphetamine, in stimulating exploratory motor behaviour, and that dextro-amphetamine is also ten times more potent than levo-amphetamine in inhibiting the re-uptake of norepinephrine, while the two drugs were equally effective in inhibiting the re-uptake of dopamine. Within this context it is important to note that phentermine is a levo-isomer which may account in part for the diminished activating effect of this drug as compared to, for instance, dextro-amphetamine or methamphetamine. This consideration is particularly important to keep in mind when comparing the findings in this thesis to other studies in the literature. With the exception of the previous experiments in Soesterberg by Trumbo and Gaillard (1975), Truijens, Trumbo and Wagenaar (1976) and Frowein and Sanders (1978), the studies in the literature most commonly used dextro-amphetamine and methamphetamine.

Psychophysiological effects. As said, amphetamines affect the sympathetic nervous system by means of their actions on norepinephrine, and this can be observed from increased heart rate, rise in blood pressure and pupil dilation. Thus, amphetamines can in principle bring about changes in all of these physiological indices, but the extent will be dependent on the dosage and type of amphetamine used. Several authors have found increased heart rate after administration of 10-15 mg dextro-amphetamine (Frankenhauser and Post, 1966; Williams and Thompson, 1973; Evans et al., 1976); Gaillard and Trumbo (1976) reported similar effects after administration of 20 mg phentermine. Similarly, it has been shown

that 5-15 mg dextro-amphetamine can bring about an increase in blood pressure (Evans et al., 1975) and pupil diameter (Bradshaw, 1970; Luria et al., 1975).

Regarding the literature on amphetamine influence on the EEG, a distinction should be made between experiments in which EEG of the resting subjects was measured, and experiments on the influence of amphetamine on task-specific EEG effects. Fink (1967) presented a review of the EEG effects in resting subjects and concludes that amphetamine brings about an increase in fast activity with decreased amplitude and desynchronization. Regarding the influence of amphetamine on task-specific EEG effects, it has been found that amphetamine increases the amplitude of the contingent negative variation (CNV) which can be observed in reaction tasks during the few seconds interval between a warning signal and the reaction signal (Kopell et al., 1974). This finding is important because the CNV can be regarded as indicative of the preparatory motor processes (Gaillard, 1978).

Effects on human performance. The influence of amphetamines on human performance was studied extensively during the 1950's, when the dangers of amphetamine usage were not yet fully recognized, and amphetamines were mainly regarded as a potential aid in counteracting fatigue and sleepiness in critical situations. A comprehensive review of this early research was presented by Weiss and Laties (1962) who concluded that amphetamine can improve performance in a variety of tasks. Although these effects could partly be attributed to motivational changes, it appears that, at least in some tasks, amphetamine also has a direct effect on performance.

That amphetamine can bring about a real improvement in performance is most clearly shown in the classic experiments by Payne and Hauty (1954), who used a multiple compensatory tracking task. When subjects performed this task continuously for four hours, the relatively small dosage of 5 mg dextro-amphetamine served to eliminate the marked decline in performance which usually occurs as a function of time-on-task. This finding has since been replicated by McKenzie and Elliott (1965), and Schroeder et al. (1974) who also found positive effects of 10 mg dextro-amphetamine in a different type of compensatory tracking task. Similarly, positive effects on pursuit tracking tasks were found by Evans et al. (1976) who used 5-15 mg dextro-amphetamine, and by Truijens et al. (1976) who used 20 mg phentermine. Similarly, the literature also indicates that various types of muscular performance tasks can be improved by amphetamine.

An extensive study by Smith and Beecher (1960) showed that 14 mg amphetamine led to better performance in different types of athletic tasks such as swimming track events and shot put. Other studies with 10-17 mg dextroamphetamine have shown improvement of grip strength (Hurst et al., 1968) and greater endurance on a bicycle ergometer task (Williams and Thompson, 1973). Furthermore, the evidence indicates that the positive influence of amphetamine cannot be easily dismissed as a mere motivational effect. In some of the Payne and Hauty studies it was found that the effect of amphetamine on tracking performance was independent of such motivational variables as knowledge of the task duration (Hauty and Payne, 1955) and feedback of performance scores (Payne and Hauty, 1955). Similarly, Smith and Beecher (1960) showed that the reward of a steak dinner for a swimming performance did not cancel out the improvement by amphetamine.

Thus, for tracking tasks and for various types of athletic tasks it has been shown that amphetamine can improve performance and that this influence is not merely the result of a change in motivation. With reference to the previous suggestion that amphetamine may affect motor control, it may be noted that both these types of tasks consist for an important part of motor responses.

On the other hand, performance on more cognitive tasks seems to be unaffected by amphetamine. Some of the older studies reviewed by Weiss and Laties (1962) show no effect of amphetamine on arithmetic and problem solving tasks and on the Digit Symbol Substitution Test. Also Quarton and Talland (1962) and Talland and Quarton (1965) found no evidence of an effect of amphetamine on the running memory span. The efficiency of visual encoding also does not seem to be affected. Kopell and Wittmer (1968) found that amphetamine had no effect on the identification of forms which were superimposed by visual noise.

Amphetamine effects have also been extensively researched in both visual and auditory vigilance tasks (N.H. Mackworth, 1950; J.F. Mackworth, 1969; Loeb et al., 1965). All these experiments show the same pattern of results. Amphetamine counteracts the considerable performance decrements which invariably occur over time in these types of tasks, but it does not improve performance beyond its initial placebo level. This in contrast with the amphetamine effect in tracking tasks, when improvements beyond the initial level have been observed (e.g. Payne and Hauty, 1954).

Because it has been reasonably well-established that the performance

decrement in vigilance tasks is attributable to a decrease in cortical arousal (Mackworth, 1969; O'Hanlon,1981) it is likely that amphetamine improves performance by counteracting this effect and keeping cortical arousal at an adequate level. Positive support for this can be found in the study by O'Hanlon et al. (1978) which showed that the performance-maintaining effect of amphetamine in a visual vigilance task was coupled to a similar effect on cortical arousal.

It is plausible to attribute this effect of amphetamine on maintaining cortical arousal to its effect on norepinephrine rather than to its effect on dopamine. As mentioned before, it has been inferred that dopamine plays a role in motor control (which is not very important in vigilance tasks) whereas norepinephrine is said to be responsible for a general increase in activity. In animal experiments, the amphetamine effect on norepinephrine is said to be responsible for an increase in exploratory behaviour (Taylor and Snyder, 1971). A similar effect can be found in human vigilance tasks, where amphetamine has been shown to increase the number of observing responses (Weiner and Ross, 1962). This point is important to note because, as mentioned before, phentermine is a levo-isomer which means that its effect on norepinephrine is insignificant when compared to the dextro-isomers commonly used in other performance studies. At the same time (as also noted before) levo- and dextro-isomers do not differ in their effects on dopamine.

In summary, the literature suggests that amphetamine improves athletic performance and performance in tracking tasks. It is plausible to attribute these effects, at least in part, to an effect on motor processes mediated by the dopaminergic action of amphetamine. Secondly, it has been shown repeatedly that amphetamine counteracts the decrement in performance during vigilance tasks, and this effect may be attributed to its effect on cortical arousal which in turn seems to be mediated by its action on norepinephrine. Thirdly, the literature shows no real evidence of an effect on cognitive functions or perceptual encoding processes.

On the nature of barbiturates

The term barbiturates refers to those compounds that are derivatives of barbiturate acid. They are classified as sedative-hypnotic agents and depending on the dosage, they are capable of producing all degrees of behavioural depression ranging from mild sedation to coma and death.

Clinical use. For clinical use, barbiturates are often classified in accordance with the duration of their action. 'Ultrashort-acting' agents such as hexobarbital and thiopental are used principally as intravenous anaestehetic agents in conjunction with nitrous oxide, while 'long-acting' barbiturates such as phenobarbital are often used as anticonvulsant agents, in the treatment of epilepsy. The 'short-acting' barbiturates such as pentobarbital and secobarbital, and the 'intermediate' acting barbiturates such as amobarbital and butobarbital are more frequently used as hypnotica or as mild sedatives. The sedative dosage is then usually one-third to one-fourth the hypnotic dosage and may be given several times daily.

Biochemical effects. The mechanism of barbiturate action on the CNS is still not well understood. Although is has recently become established that barbiturates have selective effects on synaptic transmission (Harvey, 1975; Nicoll, 1978), little can be said about the behavioural significance of these effects. It seems clear, however, that slight changes in the structure of the barbiturate molecule can bring about radically different effects in the CNS (Nicoll, 1978). This makes it more difficult to make comparisons between experiments using different types and dosages of barbiturates. However, it seems reasonably safe to generalize between different types of barbiturates, if they have a comparable dosage and duration of action (Breimer, personal communication).

Psychophysiological effects. Regarding the effects of barbiturates on psychophysiological measures, there is no evidence of a depressant effect of barbiturates on the cardiovascular system. A study by Gaillard and Trumbo (1976) even suggests a stimulating effect on the heart rate brought about by 600 mg hexobarbital.

Regarding the effects of barbiturates on the EEG, the evidence from recordings with depth electrodes in animals has indicated that lower dosages of barbiturates affect only cortical structures, and that sub-cortical structures are only affected at higher dosages (Mirsky and Tecce, 1967). Frequency analysis of human EEG recordings has shown that sedative dosages bring about a shift towards the lower frequencies associated with a low activation level (Montagu, 1971; Gaillard, 1977). Furthermore, some recent studies of barbiturate influence on the evoked potential have indicated a decrease in amplitude of the early but not the late components of the evoked potential (Otero and Mirsky, 1976; Hink et al., 1978). This would suggest that barbiturates affect the early rather than the later stages of processing.

Effects on human performance. With regard to the effects of barbiturates on human performance, a lot of the evidence comes from studies in which a battery of different tasks was used. The results from these studies are not always consistent and conclusions should be tentative.

Barbiturates have been found to have a decremental effect on such tasks as the D.S.S.T. (Mirsky and Kornetsky, 1964; Evans and Davis, 1964; Bond and Lader, 1973), different types of tapping tasks (Legge and Steinberg, 1962; Talland and Quarton, 1965; Frankenhauser and Post, 1966), and the C.P.T. (Mirsky and Kornetsky, 1964). Certain driving tasks such as parking or slowly driving between two closely spaced bollards have also been affected, while there was no barbiturate effect on the task of zigzagging between more widely spaced bollards (Betts et al., 1972). This last study suggests that judgment of distance (which is more important in the first two tasks) is more readily affected than the eye-hand coordination, which constitutes a more prominent aspect of the zigzagging task. Other studies also show no evidence of a barbiturate effect on tasks which aim to measure eye-hand coordination (Talland and Quarton, 1965; Bond and Lader, 1973). On the other hand, the literature does suggest that barbiturates affect performance in diverse tracking tasks, which also involve eye-hand coordination (McKenzie and Elliott, 1965; Borland and Nicholson, 1975; Stoller et al., 1976; Truijens et al., 1976).

There is also some suggestion that barbiturates may affect the sensitivity of the visual system and that eye movements are impaired; Misiak and Rizy (1968) found that critical flicker frequency (CFF) was increased, and Norris (1971) reported an effect of barbiturate on a smooth eye tracking task. And it has also been shown that barbiturates may have a decremental effect on an incompatible stimulus categorization task, such as the Stroop task (Frankenhauser and Post, 1966; Quarton and Talland, 1962).

Barbiturates have also been shown to affect performance in such mental effort tasks as arithmetic (Legge and Steinberg, 1962; Evans and Davis, 1969), paired-associate learning (Di Mascio, 1963 ; Mohs et al., 1977) or memory scanning (Mohs et al., 1977; MacLeod et al., 1978).

Reaction time experiments do not show very consistent findings. Bond and Lader (1973) and Trumbo and Gaillard (1975) have reported decremental effects in simple auditory RT tasks, but Frankenhauser and Post (1966) found no effect in an auditory choice task. With regard to simple visual RT tasks, there are three studies which indicate a decremental effect (Talland and Quarton, 1965; Frankenhauser and Post, 1966; Borland and

Nicholson, 1975), while in two other experiments no effect was found (Kornetsky, 1958; Trumbo and Gaillard, 1975). Similarly, the two experiments by Talland and Quarton (1965) and Bond and Lader (1973) showed that barbiturate increases visual choice RT, while no effect was found in the experiment by Kornetsky (1958).

Thus, although the literature is rather inconclusive and does not lead to well-founded conclusions about specific task parameters that are important in determining the size or occurrence of barbiturate effects, it seems that barbiturate (more than amphetamine) influences performance in various perceptual and cognitive tasks. On the other hand, there is no consistent evidence in the literature to suggest that an effect of barbiturate is specific for a particular modality, or that only perceptual and cognitive rather than motor processes are affected.

CHAPTER 4. DRUGS, SLEEP DEPRIVATION AND PROCESSING STAGES

This chapter provides a brief review of the main findings reported in the research papers in Part II, as well as some results from similar research carried out in other laboratories. It points out the consistencies and inconsistencies among the results from different experiments, and tries to account for these findings in terms of effects on serial stages such as postulated in Chapter 2.

Selective effects of amphetamine on motor stages

In the previous chapter it was suggested that amphetamine via its dopaminergic action appears to improve the efficiency of motor processes. The present results strongly support this hypothesis. As is obvious from the summary of results in Table II, the most consistent effect of amphetamine is that it shortens MT. If MT is taken as an index of response execution time, the inference is that amphetamine shortens this process. In addition, considering that response execution may involve visual feedback as well as motor output, the evidence suggests that these visual feedback processes cannot account for the amphetamine effect on MT. This may be deduced, firstly, from the observation that amphetamine also exerted an effect on MT when movements were ballistic in the sense that there was not enough time for feedback to play a role (Papers 2 and 4). Secondly, the table indicates that the amphetamine effect on MT was additive with the effect of target width. Thus, assuming that visual feedback plays a greater role in determining MT when the target is small, this finding suggests that amphetamine does not affect the efficiency of visual feedback.

With respect to the influence of amphetamine on RT, there are four experiments which showed a significant effect, while in three other experiments, there was no effect. This seeming discrepancy may be accounted for as follows. First, it is postulated that amphetamine affects the motor adjustment stage. This hypothesis is consistent with the conclusion that amphetamine improves the motor output processes during response execution because motor adjustment may be regarded as the first part of

Table II. Amphetamine effects on RT and MT in visual choice reaction tasks.

Reference and mode of response	Effects on RT			Effects on MT		
	main effect	interaction with	additive with	main effect	interaction with	additive with
Paper 2 - forward target-aiming	- no effect	- S-R compat.	- stim. degrad.	- shorter MT		
Paper 3 - expt. I - button-pressing	- shorter RT		- S-R compat. - rel. S-R freq.			
Paper 3 - expt. II - target-aiming to left or right	- shorter RT		- mov. amplit.	- shorter MT	- mov. amplit.	- target width
Paper 4 - forward target-aiming	- no effect	- time uncert. (N.S.) - accessory (N.S.)		- shorter MT		
Paper 5 - target-aiming to left or right	- shorter RT	- time uncert.	- mov. amplit.	- shorter MT		- mov. amplit.
Paper 6 - button-pressing	- no effect		- stim. intens. - mem. set size - var. vs cons. mapping			
Mohs et al. (1977) - button-pressing	- no effect		- stim. degrad. - mem. set size			

response execution occurring during RT (see Chapter 2). Second, a necessary precondition for amphetamine to influence motor adjustment is that a sufficient part of the motor output must occur during RT. This in turn will depend on the level of motor presetting achieved prior to stimulus onset. In the experiments reported in Papers 2 and 4 much motor pre-setting prior to stimulus onset could occur because the response always consisted of a forward movement, whereas in experiment II of Paper 3 and in the experiment reported in Paper 5, the alternative responses were in opposite directions and could thus not be preset to the same degree. Thus, the amount of motor adjustment that would still have to occur during RT, and hence the opportunity for amphetamine to influence this stage, would be greater in the experiments in Papers 3 and 5 than in the experiments in Papers 2 and 4.

While such a motor presetting explanation seems to fit the difference in amphetamine effects on RT between the two target-aiming tasks, it still remains to be explained why there was an amphetamine effect in the button-pressing tasks in Paper 6 and in the paper by Mohs et al. (1977). A possible reason may be that the experiments differed with respect to time uncertainty. In the Paper 3 experiment a 4 sec foreperiod was used, whereas the foreperiods in the Paper 6 experiment and in the experiment by Mohs et al. (1977) were 1 sec and 2.5 sec respectively. Thus, remembering that time uncertainty was inferred to affect the motor adjustment stage (see Fig. 1), this difference in time uncertainty between the different button-pressing tasks may account for the difference in amphetamine effects on RT. This would also be consistent with the interaction between the effects of time uncertainty and amphetamine on RT observed in Papers 4 and 5, and in the simple RT experiment by Trumbo and Gaillard (1975).

Apart from an effect on motor adjustment, there may also be an amphetamine effect on the motor initiation stage, as suggested by the (non-significant) interaction of the amphetamine effect with the effect of the accessory on RT (Paper 4). But none of the other processing stages postulated in the model of Fig. 1 seem to be affected. There is no evidence of an effect on stimulus pre-processing or encoding, because the amphetamine effect was additive with the effects of stimulus intensity and degradation; and there is no evidence of an amphetamine effect on

response programming because its effect on RT was additive with the effect of movement amplitude (Paper 3, experiment II; Paper 5).

With regard to the effect of amphetamine on response selection the findings are less equivocal. In one experimnet it was found that amphetamine appeared to lengthen RT in the incompatible condition whereas it had no effect in the compatible condition. This would suggest a negative effect of amphetamine on response selection. However, this interaction was not replicated in a subsequent study which also showed additivity of amphetamine with relative signal frequency. Because relative signal frequency interacts with S-R compatibility and can therefore be assumed to affect the response selection stage, the evidence on the whole tilts towards the conclusion that amphetamine has no effect on response selection.

In addition, there is no evidence of an amphetamine effect on the memory comparison stage in a Sternberg memory search task. (See Paper 6 for a description.) The experiments described in Paper 6 as well as in the Mohs. et al. (1977) paper indicated no main effect of amphetamine and no interaction between the effects of amphetamine and memory set size on RT. Moreover, the lack of interaction between the effect of amphetamine on RT and the effect of consistent versus varied mapping (Paper 6), indicates that it makes no difference whether information processing within the memory comparison stage is (in the meaning of Schneider and Shiffrin, 1977) "automatic" or "controlled". In neither case does amphetamine appear to affect this stage.

Thus, the general conclusion which emerges is that of the various information processing stages in a choice reaction task, amphetamine only affects the motor output stages.

Of course, this conclusion is largely based on experiments with phentermine. As pointed out in the previous chapter, phentermine is a levo-isomer whereas most other studies have used dextro-isomers. Although the dopaminergic action of levo-isomers and dextro-isomers is similar, the latter have a much stronger effect on norepinephrine (Taylor and Snyder, 1971); and it appears that it is this effect on norepinephrine rather than the effect on dopamine which accounts for the effect of amphetamine in counteracting performance decrements during long boring vigilance tasks. With respect to the present results, the question is whether a dextro-isomer would show the same selective effect as phentermine or whether other stages would also be affected, thus leading to larger overall effects on RT.

On first impression, the answer seems to be negative. As is evident for instance from the reviews by Weiss and Laties (1962) and Sanders and Bunt (1971), the observed amphetamine effects with dextro-isomers have usually been small and sometimes totally absent. The data by Mohs et al. (1977) who used methamphetamine support this conclusion. On the other hand, it could be speculated that dextro-amphetamine would have a stronger effect on the motor initiation stage (see Chapter 2). The existence and nature of this stage is of course in itself already speculative, but let us suppose that this stage does what Sternberg et al. (1980) denote as motor command, i.e. the decision to do something as distinct from the decision about what should be done (response selection) or how it should be done (motor programming). If this description of the motor initiation stage is correct, it may well be that the effect of amphetamine on norepinephrine, which is said to bring about an increase in exploratory behaviour in rat experiments and in the number of observing responses in human vigilance experiments, may also cause an increase in "response readiness" (see Chapter 2). Referring back to Fig. 1, dextro-amphetamine should then show a larger interaction with the effects of both time uncertainty and accessory than has now been observed for phentermine.

The selective effect of barbiturate on encoding

As can be inferred form Table III, the findings suggest that the effect of barbiturate on processing stages is quite selective. The only interaction of barbiturate was with the effect of stimulus degradation on RT. This indicates an effect on stimulus encoding. This selective effect was observed in four different experiments carried out in two different laboratories. Given the fact that different studies on the effects of drugs and other stresses often lead to contradictory findings, it is gratifying to see such consistency.

With respect to the other effects of barbiturate, the following points are relevant. Firstly, barbiturate had no effect on response execution; at least not when the executed response consisted of a short ballistic movement with no opportunity for visual feedback to affect MT (i.e. Papers 2 and 4). Secondly, barbiturate had a relatively large effect on RT, but this effect was additive with most of the task variables. Thus, the additivity of the barbiturate effect with the effects of S-R compatibility, accessory and time uncertainty indicates that barbiturate has no effect on response selection, motor initiation or motor adjustment. Thirdly,

Table III. Barbiturate effects on RT and MT in visual choice reaction tasks.

	Effects on RT			Effects on MT
	main effect	interaction with	additive with	main effect
Paper 2	- longer RT	- stimulus degradation	- S-R compatibility	- no main effect - no interactions
Paper 4	- longer RT		- accessory time uncertainty	- no main effect - no interactions
Paper 6	- longer RT		- stimulus intensity - memory set size - varied versus consistent mapping	
Paper 7	- longer RT	- stimulus degradation (N.S.)	- stimulus intensity	
Mohs et al. (1977)*	- longer RT	- stimulus degradation	- memory set size	
Rundell et al. (1978)*	- longer RT	- stimulus degradation	- memory set size	
Williams et al. (1981)*	- longer RT	- stimulus degradation	- memory set size	

* These authors used secobarbital in dosages comparable to our pentobarbital dosages

there are three experiments which indicate that the barbiturate effect is additive with memory set size, and one of these (Paper 6) also shows additivity with varied versus consistent mapping. Thus, just as was the case with amphetamine, there is no evidence of a barbiturate effect on the memory comparison stage, irrespective of whether processing within this stage is "automatic" or "controlled". Fourthly, it appears that barbiturate affects late rather than early stimulus processing. This may be deduced from the apparent additivity with stimulus intensity (Paper 7), and from another recent experiment by Frowein et al. (1981) which shows that the effect of barbiturate on RT is independent of stimulus modality. The same conclusion can also be derived from the EEG data reported in Paper 7.

Sleep deprivation and processing stages

With respect to the effects of sleep deprivation, two experiments are most relevant: the experiment described in Paper 5 and a recent study by Sanders et al. (1981). From the experiment reported in Paper 5, it appears that sleep deprivation (like amphetamine) affects the response execution stage as well as the preceding motor adjustment stage. This is evident from the sleep deprivation effect on MT, and from the interaction of sleep deprivation with the effect of time uncertainty on RT, although the latter may also suggest an effect on motor initiation (See Fig. 1). It is also consistent with the observed interaction between the effects of sleep deprivation and amphetamine on RT, although it should be noted that the interaction of these two variables on MT was not significant, and that the effect of sleep deprivation (unlike amphetamine) was additive with the effect of movement amplitude on MT.

In addition, the study by Sanders et al. (1981), has shown a large interaction of the effect of sleep deprivation with the effect of visual stimulus degradation on RT, while the relationship between the effects of sleep deprivation and S-R compatibility on RT was additive. Thus, it seems that sleep deprivation not only affects the motor output stages, but also that it affects the stimulus encoding stage. Yet, the additivity of sleep deprivation with S-R compatibility shows that is has no overall effect in the sense that all stages are affected.

CHAPTER 5. IMPLICATIONS FOR THEORIES OF AROUSAL AND ATTENTION

Most theories about the influence of stresses on performance are theories of arousal and attention. They try to explain these effects in terms of changes in the availability or allocation of the resources required for task performance. This differs from the present structuralist approach, which investigates the effects of stresses on processing stages, irrespective of the resources which may or may not be required by those processing stages. In principle, however, the two approaches are not necessarily inconsistent, because it is quite conceivable that an effect of a particular stress on one or more processing stages is mediated by an effect of that stress on the availability or allocation of resources. To consider this possibility, this chapter relates some of these theories to the findings reported in the previous chapter.

Unidimensional arousal theory

The simplest and most common explanation of the effects of stresses on performance is that they exert their influence by either increasing or decreasing the organism's level of general arousal. This hypothesis was particularly prevalent during the fifties and early sixties (Hebb, 1955; Malmo, 1959; Berlyne, 1960), and it is still popular because of its simplicity and intuitive appeal. Usually, it is coupled to the so-called Yerkes-Dodson law, which states that performance is related to arousal in the form of an inverted U, and that the optimum level of arousal is lower for more difficult tasks. Although some of the arousal theorists of the fifties doubted the validity of the Yerkes-Dodson law (e.g. Duffy, 1957), they still maintained that arousal should be regarded as unidimensional and aspecific. In more recent years, this view has become increasingly untenable, firstly, because of the well-known physiological research by Lacey (1967) and secondly, on the basis of analyses of the behavioural effects of different stresses (e.g. Broadbent, 1971). It is also clear that a unidimensional arousal theory cannot account for the selective effects of amphetamine and barbiturate in the present study. It would be more in line with the unidimensional view that all and not just one or two of the processing stages would be affected; and a unidimensional arousal theory could certainly not explain why, for example, stages on the motor output side of information processing (i.e. motor adjustment and

response execution) are affected when arousal is lowered by sleep deprivation, while these stages are not affected when arousal is lowered by a barbiturate.

The Easterbrook-Hockey hypothesis of attentional shift

A theoretical link between the arousing properties of stresses and their consequences for cognitive functioning was introduced by Easterbrook (1959). To account for the Yerkes-Dodson law, he postulated that high arousal causes the organism to restrict the range of cues which guide his responses, while low arousal has the opposite effect. Thus when arousal is too low, irrelevant cues will play a role in determining responses, and performance will suffer; when arousal increases, irrelevant cues are less likely to determine responses, and performance will improve accordingly; but when arousal increases further, the restriction of cues will also extend to the relevant cues and performance will suffer again. Most subsequent work on the Easterbrook hypothesis was done by Hockey (1970a, b), who emphasized that the restriction of cues with increased arousal involves a narrowing of attention rather than a decrease in peripheral vision.

In more recent papers together with Hamilton (Hamilton et al., 1977; Hockey et al., 1981), Hockey has left the unidimensional view of arousal of the original Easterbrook hypothesis and his earlier papers. Instead, a multi-dimensional concept of activation is adopted in which stresses may have highly specific effects on information processing. However, a central idea in these later papers, which relates back to the Easterbrook hypothesis, is the idea that a stress will bring about an attentional shift, which means that some parts of information processing go better while others go worse. This idea seems to fit the results which Hockey and Hamilton obtained in their work on noise and alcohol. For example, in a running memory task, Hamilton et al. (1977) found that noise improved the recall of recent items, but impaired the recall of earlier items.

The question is whether attentional shifts such as these, represent a general principle or whether they just happened to occur for the stresses and tasks used by Hockey and Hamilton. The present results suggest the latter. The only finding which could be regarded as consistent with a processing shift interpretation is the tendency (reported in Paper 2) for amphetamine to slow down response selection while speeding up response

execution. However, only the facilitating effect of amphetamine on response execution was confirmed in subsequent experiments (Papers 3, 4 and 5) while the inhibitory effect on response selection was not replicated (Paper 3, experiment 1) and may represent a spurious result. Regarding the effects of barbiturate and sleep deprivation, there was no evidence that their detrimental effects on selected stages are either partly or completely offset by more positive effects on other stages.

Pribram and McGuiness

Another current theme in discussions of attention (e.g. Sanders, 1979; Navon and Gopher, 1980) is that the resource requirements of information processing do not derive from a single resource reservoir, but must involve multiple resources which are functionally linked to different aspects of information processing. This idea has been worked out most specifically in the neuropsychological theory by Pribram and McGuiness, (1975). They postulate that the control of attention involves three systems. The first system, denoted as the "arousal" system, regulates the phasic arousal responses in the brain which are associated with the orientation reaction (Lynn, 1966) and which are elicited by stimulus changes of the type that Berlyne (1969) described as collative variables(e.g. sudden changes in intensity, the presentation of unfamiliar stimuli, etc.). The second system controls the preparatory readiness of response mechanisms. And the third system regulates and coordinates arousal and activation to ensure the efficiency of information processing. This system requires effort and is said to be important during reasoning activity and for maintaining an adequate level of vigilant readiness when arousal and activation are low.

Relating Pribram and McGuiness' theory to the effects of amphetamine, it seems fairly obvious that the effects of amphetamine on motor output stages could be mediated by the "activation" system which is said to control the preparatory readiness of response mechanisms. Secondly, it is also conceivable that amphetamine affects the system which regulates "arousal". Arousal in the sense of Pribram and McGuiness is a phasic effect, which seems to overlap with Sanders' concept of "immediate arousal" (e.g. Sanders and Wertheim, 1973) and may be elicited by an auditory accessory stimulus in a visual choice task (see Paper 4). Thus, if the weak interaction between the effects of amphetamine and the accessory on RT could be confirmed in subsequent research it could be interpreted

as an effect of amphetamine on the regulation of arousal. This, of course, also corresponds to the already suggested explanation of the effect of amphetamine on maintaining performance during vigilance (see Chapter 3). Thirdly, it does not appear from the present findings that amphetamine affects the effort system. Although there is no obvious relationship between Pribram and McGuiness' concept of effort, it is said to be related to reasoning which comes close to Shiffrin and Schneider's (1977) controlled processing. Thus, if amphetamine affects the effort system and if controlled processing involves effort, the effect of amphetamine on RT should interact with the effect of memory set size and with the effect of varied versus consistent mapping. As shown in Table II of Chapter 4, the findings do not confirm this prediction.

From the above, it may be concluded that the inferred amphetamine effects on various processing stages, could quite plausibly be accounted for in terms of a theory of attentional control such as postulated by Pribram and McGuiness. More specifically, it appears that amphetamine affects the activation system and possibly also the arousal system, but that amphetamine has no effect on the effort system.

Relating the barbiturate findings to the theory of Pribram and McGuiness leads to quite a different picture. The lack of a barbiturate effect on motor output stages, its additivity with the accessory effect on RT, and finally its additivity with the effects of memory set size and varied versus consistent mapping, lead to the conclusion that barbiturate has no effect on either the activation system, the arousal system or the effort system. The encoding stage which was the only stage on which a barbiturate effect was evident seems to involve none of the attentional control systems postulated by Pribram and McGuiness. It appears to be an automatic process which occurs without the intervention of attentional control mechanism. This is also supported by for instance the double task experiments of Logan (1978) which showed that encoding makes no demand on attention, whereas memory comparison does.

Top-down versus bottom-up processing

The inference that the effect of one stress (amphetamine) may be accounted for in terms of attentional control mechanism, whereas the effect of another stress (barbiturate) seems to have a direct effect on stimulus processing, is important for what may be called the "top-down versus bottom-up issue". In brief, this refers to whether stresses affect performance

through active attentional control mechanisms (top-down) or through automatic processing (bottom-up). In recent years it has been argued (e.g. Broadbent, 1977; Rabbitt, 1979; Hockey, 1979) that the effects of stresses on performance can only be properly understood in terms of changes in top-down processing. In this view a linear stage model only relates to bottom-up processing and is therefore a bad theoretical framework for stress research (Rabbitt, 1979).

To answer this criticism, it could be argued that some stages are not just passive-automatic but require active control. For instance, the memory comparison stage in the memory search tasks may require "controlled" processing (Schneider and Shiffrin, 1977). Also within the model in Fig. 1, the "motor initiation" and "motor adjustment" stages should be regarded as subject to active control, although most of this control would at least partly take place during preparatory processes before the stimulus onset.

Nevertheless, it seems reasonable to assume that most of the stages in the reaction process involve automatic rather than attentional processes. Thus, the real issue is whether the likely locus of stress effect is top-down or bottom-up. In this respect, the inferred barbiturate effect on encoding is important, because it shows not only that a stress (barbiturate) may effect an automatic process (encoding), but also that such an effect may be highly selective in the sense that other automatic processes (for instance stimulus preprocessing) are not affected.

Conclusions and suggestions for further research

Taking into account both the amphetamine and the barbiturate findings, the general conclusion which emerges from the discussion in this chapter, is that stresses may affect automatic as well as attentional processes, and that on the level of attentional control as well as on the level of automatic processing these effects are likely to be selective instead of general.

It follows from this conclusion that, particularly in exploratory research, the investigator should not be guided by prior general assumptions about the effects of stresses on attentional control. A research approach which, in first instance tries to account for the effects of a stress on task performance in terms of the structural processes involved in carrying out the task, is more appropriate because it does not depend on such prior assumptions. Only if it is relatively clear which of the

structural processes are affected, should research be directed at the analysis of the attentional mechanisms which may or may not be involved in mediating these effects.

The present thesis, which tries to relate stress effects to the processing stages in reaction time, is one specific example of this approach, but there are of course other possibilities. For instance, in the field of memory research, recent investigations of the effects of alcohol and marihuana on memory processes have indicated selective effects of these drugs on storage while retrieval seems to remain unimpaired (e.g. Wickelgren, 1975; Miller et al., 1978; Darley and Tinklenberg, 1974). However, a precondition for this type of research is of course that the information processing structure of the experimental task is reasonably well-understood. This, of course, limits the choice of tasks.

If the stage analysis approach to stress research is to be continued, it may be useful to complement the RT-data with other evidence. The concurrent registration of evoked potentials with the aim of establishing links between EP components and processing stages, seems a potentially fruitful line of research. The last experiment in this thesis (Paper 7) is a first tentative step in that direction.

With respect to the choice of drugs in future experiments of this nature, it is advisable to select drugs with well-known biochemical effects in the brain (i.e. effects on neurotransmitters). In particular, if a drug has a well-established and selective effect on a specific type of neurotransmitter, a stage analysis approach such as followed in this thesis may not only lead to inferences about the effects of that drug on stages in information processing, but it also becomes possible to find out more about the biochemical nature of information processing.

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PART II: RESEARCH PAPERS

PAPER 1

EFFECTS OF VISUAL STIMULUS DEGRADATION, S-R COMPATIBILITY, AND FOREPERIOD DURATION ON CHOICE REACTION TIME AND MOVEMENT TIME[*]

Summary

In a 2 by 2 by 2 factorial experiment, 12 subjects carried out a choice reaction time task. Independent variables were foreperiod duration (1.5 sec vs. 10.5 sec), stimulus degradation, and stimulus-response (S-R) compatibility. The speed of the response was measured in terms of reaction time (RT) and movement time (MT). The data showed additive effects of foreperiod duration (FPD), S-R compatibility, and stimulus degradation on RT. None of these variables had an effect on the MT. This is consistent with the hypothesis that stimulus encoding, response selection, and response execution represent independent processing stages, and suggests that FPD affects none of these stages.

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Introduction

When a subject has to make a rapid response to a signal, reaction time (RT) is shortened if the reaction signal is preceded by a warning signal. As the foreperiod duration (FPD9 between warning signal and reaction signal decreases, the RT decreases until some optimal foreperiod is reached (e.g. Alegria, 1974; Bertelson, 1967; Sanders, 1972). Although several explanations have been proposed (e.g. Posner et al., 1973; Sanders, 1977), the locus of the effect in the information flow has not as yet been conclusively determined.

A systematic approach to investigate this issue could be through the additive factor method (Sternberg, 1969), which assumes that different task variables affect different processing stages if they show additive contributions to RT, while an interaction between the effects of different task variables is assumed to indicate that these variables affect the same processing stage. Although the assumption that additivity implies separate processing stages has recently been criticized (Taylor, 1976), application of the additive factor method to the existing data shows a fairly consistent picture of processing stages.

Thus, regarding FPD, additive contributions have been observed with visual stimulus intensity (Raab et al., 1961; Sanders, 1975) and with stimulus-response (S-R) compatibility (Posner et al., 1973; Sanders, 1977). Considering this in conjunction with the finding that both stimulus intensity and stimulus degradation show additive effects with S-R compatibility (Sanders, 1977; Sternberg, 1969), it would seem that response selection constitutes a processing stage that is independent of stimulus processing and that FPD affects neither encoding nor response selection. The present experiment constitutes a further test of this conclusion by investigating the effects of FPD, stimulus degradation, and S-R compatibility in the same reaction task.

Second, the experiment investigated whether FPD and the other two task variables have an effect on response execution. Fitts (1954) observed that movement time (MT) was not affected by the number of alternatives in a choice reaction task, suggesting that RT and MT represent independent processes and that MT can be used as a measure of response execution independent of information processing. For this reason, both RT and MT were measured in the present experiment. Thus, if information processing and response execution constitute independent processes, there

should be no effect of stimulus degradation and S-R compatibility on the MT. Furthermore, an effect of FPD on the MT could then be interpreted as an effect of FPD on response execution as distinct from information processing.

Method

Subjects

The subjects were 12 male students from the University of Utrecht, with an age range from 20 to 30 years. The subjects were paid Hfl. 60,- for participating in the experiment.

Task and apparatus

The task was a visual four-choice reaction task with RT and MT as the response measures. The subject was seated in a sound-attenuating cubicle at a sloping desk. The stimulus situation is schematically presented in Fig. 1. The visual signals consisted of flashes generated by a Nixie tube situated about 1 m in front of the subject. The warning signal (S_1) consisted of a 500-msec flash of the Nixie tube with all elements activated,

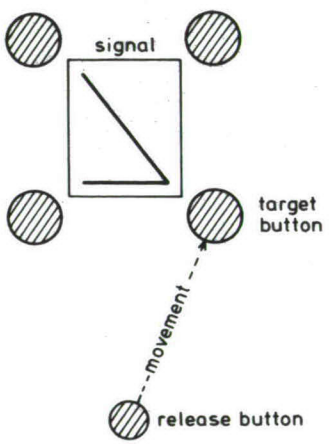

Fig. 1. Schematic representation of the stimulus situation

and the imperative signal (S_2) consisted of a 200-msec flash of a diagonal and horizontal line meeting at one of the four corners of the Nixie tube. The FPD, defined as the interval between the onset of S_1 and the onset of S_2, was either 1.5 or 10.5 sec. The intertrial interval was always 5 sec. The index finger of the subject's preferred hand was resting on the release button, and his task was to make a movement with his index finger to press one of the four target buttons. The distance between the release button and the target button was 13 cm for the two bottom target buttons and 20 cm for the two top target buttons. The subjects were specifically instructed that the warning signal served to prepare for a fast response and that, once the movement was initiated, it should be made as rapidly as possible without hesitation about which button to press. They were also instructed to work as accurately as possible.

Compatibility was varied in the following manner. The correct target button in the compatible condition was the joining point of the two lines (the bottom right button in Fig. 1), while the correct response in the incompatible condition was to press the next target button going in counterclockwise direction (in the illustration shown in Fig. 1, the upper right button). Stimulus degradation was achieved by superimposing a photonegative with a visual noise pattern upon the surface of the Nixie tube. The noise pattern consisted of a cluster of black nonsense shapes, each averaging about 1 mm in diam. The light-to-dark ratio was about 30%. To avoid differences in light intensity between the two conditions, a similar photonegative without visual noise was used for the undegraded condition. The preprogrammed signal presentation and the registration of the responses was performed by the PSARP system (Van Doorne and Sanders, 1968). This allowed the measurement of RT, defined as the interval between the onset of the imperative signal and the release of the release button, and MT which was defined as the interval between the release of the release button and the pressing of the target button.

Design and procedure

A 2 by 2 by 2 factorial design was used, with stimulus degradation (undegraded vs. degraded), S-R compatibility (compatible vs. incompatible), and FPD (1.5 sec vs. 10.5 sec) as the independent variables. Experimental conditions were varied between blocks of 20 trials, of which the first 5 were regarded as warm-up trials to be used in the data analysis. The order of presentation of the compatibility and degradation conditions

was counterbalanced in the manner of a Latin square design, with degradation nested within compatibility; the order of presentation of the two FPDs was partially counterbalanced within degradation conditions. Two blocks with different foreperiods, but the same compatibility and degradation conditions, were carried out one after the other with a 2-min rest period in between, while blocks differing in compatibility and/or degradation were always separated by a 20-min rest period. Subjects were trained for 1 whole day prior to the experiment. On the day of the experiment the whole sequence of conditions was run twice so that there were two blocks for each experimental condition. Hence, the total number of trials used in the analysis was 2(FPD) by 2(compatibility) by 2(degradation) by 12 (subjects) by 2 (blocks) by 15 (trials per block) = 2,880 trials.

Results

For each experimental condition, the data of the two blocks were combined, and the average RTs and MTs were pooled over different response keys and computed for each subject. The group means are shown in Fig. 2.

The analysis of variance for RTs showed significant effects of stimulus degradation $|F(1,11) = 56.7,\ p < .01|$, S-R compatibility $|F(1,11) = 380,\ p < .01|$, and FPD $|F(1,11) = 28.1,\ p < .01|$. There were no significant interaction effects on RT. A separate analysis of variance on the MTs showed no significant effects of degradation or FPD. Although Fig. 2 suggests a small effect of S-R compatibility on the MT, this effect was not statistically significant $|F(1,11) = 3.45|$. Interactions were also nonsignificant.

The error scores presented in Table I also include trials in which the subject failed to press the target button and trials in which the subject was assumed to hesitate during the movement. Because it came obvious during the training sessions that most movement times fell between 100 and 150 msec, and that hesitation resulted in considerably longer MTs, a criterion of 200 msec was decided upon to eliminate "hesitations" from the analysis of MTs. Thus, trials with MTs longer than 200 msec were categorized as errors. Table I shows small differences as a function of stimulus degradation, compatibility, and FPD, but an analysis of variance showed neither significant main effects nor interactions of these variables ($p > .10$).

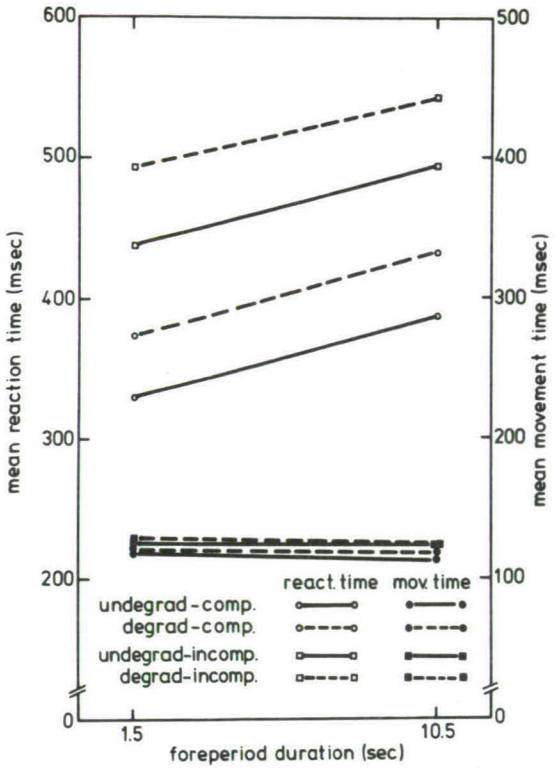

Fig. 2. Reaction time and movement time as a function of S-R compatibility, stimulus degradation, and foreperiod duration.

Table I. Mean percentages of errors.

Foreperiod	1.5 sec	10.5 sec
Compatible-Undegraded	3.9	4.2
Compatible-Degraded	5.6	6.9
Incompatible-Undegraded	6.9	7.5
Incompatible-Degraded	7.5	8.9

Discussion

These results confirm those of Sternberg (1969) with respect to the additive contributions of stimulus degradation and S-R compatibility to RT. The fact that the differences in experimental setting between Sternberg's and the present study did not change the picture, suggests that the distinction between "encoding" and "response selection" as stages in the choice reaction process is quite robust. Second, the data show that neither stimulus degradation nor S-R compatibility affected the MT. This suggests that, when response execution consists of a short rapid movement, it occurs in succession to the information processing stage contributing to choice RT. It also extends Fitts' (1954) finding that the number of alternatives affects the RT but not the MT.

Regarding the FPD effect, the data show that the effect of FPD on RT was additive to the effects of stimulus degradation and S-R compatibility, and that FPD had no effect on MT. This is consistent with the conclusion that encoding, response selection, and response execution are not affected by FPD.

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PAPER 2

SELECTIVE EFFECTS OF BARBITURATE AND AMPHETAMINE ON INFORMATION PROCESSING AND RESPONSE EXECUTION*

Summary

In a 3 x 2 x 2 factoral experiment, 12 subjects carried out a choice reaction task with reaction time (RT) and movement time (MT) as response measures.

Independent variables were drug treatment (amphetamine, barbiturate, placebo), visual stimulus degradation and S-R compatibility. Visual stimulus degradation and S-R compatibility showed additive effects on the RT, but did not affect the MT. This confirms that stimulus encoding, response selection and response execution represent independent processing stages. The two drugs had selective effects on the RT and the MT. Barbiturate (as compared to placebo) had no effect on the MT, but it lengthened the RT, and this effect was additive with the effects of S-R compatibility but showed an interaction with the effects of stimulus degradation. Amphetamine (as compared to placebo) shortened the MT, but there was no significant main effect of amphetamine on the RT although the interaction with the effect of S-R compatibility was significant. These results suggest that barbiturate affects stimulus encoding whereas amphetamine affects response-related processes.

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Introduction

This study is part of a project in which the effect of a barbiturate and an amphetamine derivative are investigated in various types of reaction tasks. The strategy of this research consists of trying to identify task variables which are important for the occurrence or size of these drug effects. The idea behind this is that, if these task variables can be related to specific processes or mechanisms which are important in determining performance, it should also be possible to infer something about the effect of that drug on those processes.

When looking for processes that could account for the effects of stimulant and depressant drugs such as amphetamines and barbiturates on performance, it seems obvious to suggest that they affect performance by affecting some sort of arousal mechanisms. This idea featured prominently in two previous experiments carried out within this project. In the first experiment, Trumbo and Gaillard (1975) found that barbiturate lengthened the simple RT when the signal consisted of a loud tone, but had no effect when the signal was a small light. Conversely, amphetamine had no effect in the auditory condition but it reduced the RT in the visual condition. To account for this, they suggested that a loud auditory stimulus exerts an "immediately arousing" effect while the visual stimulus would not. It was postulated that barbiturate may act to depress performance by reducing the effect of immediate arousal, while amphetamine could be beneficial when the stimuli themselves are not immediately arousing and it is therefore more difficult to maintain an adequate level of preparation. A similar but more general hypothesis is that depressants such as barbiturates have their greatest effect when the task is somehow arousing, while stimulants such as amphetamines have a greater effect when the task condition is not arousing. This more general hypothesis was also consistent with a subsequent experiment by Frowein and Sanders (1978a) whose findings suggested that barbiturate has a greater effect on RT when the task involves time stress, and that amphetamine is more likely to affect performance when there is no time stress.

There are, however, some problems with trying to explain such task-specific drug effects in terms of changes in arousal. Firstly, it has become increasingly clear that arousal is a more complex phenomenon than thought of at first. Recent activation theories such as postulated by

Broadbent (1971), Pribram and McGuiness (1975) and Hamilton et al. (1977) all postulate that there must be different types of arousal, but there is little agreement among these different theories when it comes to deciding upon the nature or number of these different arousal types. Hence, the operationalization of specific types of arousal in terms of task conditions remains a somewhat arbitrary matter. Secondly, and perhaps more importantly, arousal theories are concerned with postulating general or specific changes in the state of the organism, but they usually do not specify what this means in terms of the processes or mechanisms which are necessary to perform a particular type of task. For instance, while Trumbo and Gaillard (1975) proposed that amphetamine may have facilitated the maintenance of arousal when this was not elicited by signals themselves, they suggested that this may have occurred either by improving receptor orientation, or by increasing the subjects' ability to maintain motor preparation or to maintain their attention on the task.

An alternative approach to the study of drug effects on performance consists of trying to account for these effects in terms of the component processes which are necessary to carry out the task. A suitable framework for this is provided by Sternberg's additive factor method. According to the logic of this method, it can be inferred that different task variables affect independent processing stages if they show additive contributions to the reaction time, while an interaction between the effects of different task variables can be assumed to indicate that these variables affect the same processing stage (Sternberg, 1969). The additive factor method has been widely used for the identification of processing stages, and one of the most consistent findings has been that the effects of visual stimulus degradation and S-R compatibility are additive (e.g. Sternberg, 1969; Shwartz et al., 1977; Sanders, 1980). Thus it can be inferred that visual stimulus degradation and S-R compatibility affect two consecutive processing stages which may be called stimulus encoding and response selection. The logic of the additive factor method can also be applied to the relationship between the effects of drugs and the effects of task variables. If a drug and a task variable show an interaction in their effect on the RT, it can be inferred that drug and task variable affect a common processing stage, while additivity implies that they affect separate processing stages. Some examples of an additive factor approach to the study of drug effects are the investigations on marihuana by Darley et al. (1973) and on alcohol by Tharp et al. (1974). The latter study in-

dicated that alcohol consistently impaired response selection but had no effect on stimulus encoding. Also, the additive relations between task variables were unaffected. This indicates that a drug may selectively affect separate stages while the relation between these stages remains unaffected. In the present experiment, the effects of barbiturate and amphetamine were investigated in a task taken over from a previous experiment by Frowein and Sanders (1978b), in which the subject was presented with a visual signal and had to make a short ballistic movement to one of four targets. In this manner the movement time (MT) could be measured as a separate and consecutive measure to the RT. The results obtained by Frowein and Sanders showed that stimulus degradation and S-R compatibility had additive effects on the RT but that they did not affect the MT. Therefore it was concluded that the MT in this type of task represents a stage which is independent of the preceding stage of stimulus encoding and response selection.

The purpose of the present experiment was to find out whether either amphetamine or barbiturate have an effect on stimulus encoding, response selection or response execution. The task variables were again visual stimulus degradation and S-R compatibility, and the response measures were reaction time and movement time. Thus, a selective drug effect on visual encoding should be evident from an interaction with degradation, while a drug effect on response selection should result in an interaction with the effect of S-R compatibility on the RT. Similarly, if a drug selectively affects response execution it should show an effect on movement time and not on reaction time; and if a drug affects all three processing stages it should affect both reaction time and movement time and show an interaction with each of the two task variables.

Method

Subjects

The subjects were twelve healthy male students from the University of Utrecht with an age from 20 to 30 years. Two weeks before participating in the experiment, all subjects received a medical examination and were informed about the nature of the drug treatment and the experimental conditions. They were paid Hfl. 60,-- a day for participating in the experiment and an extra bonus of approx. Hfl. 5,-- to Hfl. 10,-- a day was awarded on the basis of their performance during the experimental task.

Drug treatment

The treatment conditions consisted of an amphetamine derivative (20 mg Phentermine HCl), a barbiturate (100 mg pentobarbital sodium) and a placebo. Each subject received the three treatment conditions on separate days at weekly intervals. Treatment was always administered at 9.00 or 9.30 a.m. by means of a suppository, and the experimental session began 1½ hours after treatment and finished about 3½ hours later. The pharmacokinetic research by Breimer (1974) and Vree (1973) shows that this should ensure a relatively stable plasma concentration during experimental sessions. Allocation of the drug treatment was "double-blind", i.e. neither the subjects nor the experimenter knew on which days the different treatments would be administered.

Experimental task and apparatus

The task was a visual four-choice reaction task with reaction time and movement time as the response measures. The subject was seated at a sloping desk in a sound attenuated cubicle. The visual signals consisted of flashes generated by a Nixie tube situated about one meter in front of the subject. The imperative signal consisted of a 200 msec flash of a diagonal and a horizontal line joining in one of the four corners of the Nixie tube. This stimulus situation is schematically represented in Fig. 1. The index finger of the subject's preferred hand was resting on the release button, and his

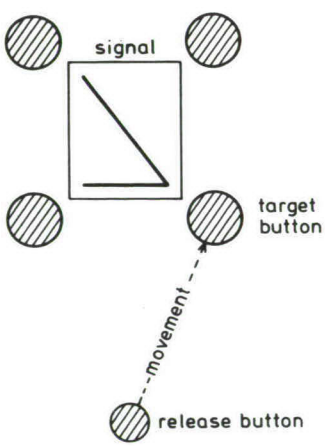

Fig. 1. Schematic representation of the stimulus situation.

task was to make a movement with the index finger to press one of the four target buttons. The distance between the release button and the target button was 13 cm for the two bottom targets and 20 cm for the two top targets. The imperative signal was always preceded by a warning signal, consisting of a 500 msec flash with all elements activated. The inter-stimulus interval between the warning signal and the imperative signal was always one second, and the interval between successive imperative signals was always five seconds. Subjects were specifically instructed that the warning signal served to prepare for a fast response, and that once the movement was initiated it should be made as rapidly and accurately as possible without hesitation about which button to press.

They were told that a bonus would be computed on the basis of reaction speed, but that no bonusses would be paid for sessions with more than 3% errors. The preprogrammed signal presentation and the registration of the responses was performed by the PSARP system (Van Doorne and Sanders, 1968). The reaction time (RT) was defined as the interval between the onset of the imperative signal and the release of the release button, and the movement time (MT) was defined as the interval between release of the release button and pressing of the target button.

The task variables were S-R compatibility and visual degradation, S-R compatibility was varied as follows: the correct target button in the compatible condition was indicated by the joining point of the two lines (the righthand bottom target in Fig. 1), while the next target button in counter clockwise direction represented the correct response in the incompatible condition (i.e. the upper right-hand button in Fig. 1). Visual stimulus degradation was achieved by superimposing a photonegative with a visual noise pattern upon the surface of the Nixie tube. The noise pattern consisted of a cluster of black nonsense shapes, each averaging about 1 mm in diameter. The light to dark ratio was about 20%. To avoid differences in light intensity between the two conditions a similar photonegative without noise was used for the undegraded condition.

Design and Procedures

Drug treatment (barbiturate, amphetamine, placebo), S-R compatibility and stimulus degradation were varied in a within-subjects design. Thus, each subject carried out the reaction task under three treatment conditions and four task conditions. Treatment conditions were varied between days, while S-R compatibility and visual stimulus degradation were varied

between sessions but within days. There were 300 trials presented during each session. The order of presentation was varied in the manner of a nested Latin square with the order of S-R compatibility conditions nested within the order of treatment conditions, and the order of degradation conditions nested within the order of S-R compatibility conditions.

For each subject the program consisted of two training days and three experimental days at weekly intervals. During each experimental day, two subjects were alternately tested on each of the four task conditions. Each task condition was tested for a 25-minute session, and there was a 30-minute rest-period between sessions . Subjects were alternately run, so that one subject was tested while the other was resting. The first subject received the drug treatment at 9.00 a.m. and the first experimental session was at 10.30 a.m., while the program for the second subject started 30 minutes later.

Results

The principal measures of performance were the means of RT's and MT's. These were computed for each individual session and analyzed by separate analyses of variance. The three drug treatment conditions were not analyzed as one variable in these analyses of variance, but separate planned comparisons were made for the effects of barbiturate and amphetamine against placebo. Furthermore, to provide some form of check that the effects of these two drugs and their relationship with the effects of task variables were no artifact of the within-subjects design (Poulton, 1973), the data obtained during the first experimental week were separately looked at. This gives some idea as to whether different types of results would be obtained with drug treatment as a between-subjects variable. Suffice to say that this additional inspection of the data suggests that, if anything, the effects on RT's and MT's described below were more prominent with a between-subjects design. The percentages of errors and omissions were also analyzed for each individual session, but very few errors and omissions were made (below 1% for all sessions). Therefore, no additional analyses of variance were carried out on these measures.

Reaction times

Effects of S-R compatibility, stimulus degradation and drug treatment on the mean RT's are shown in Fig. 2. Analysis of variance showed signifi-

cant main effects of S-R compatibility ($F = 443.25$; $df = 1,24$; $p < .01$) and visual degradation ($F = 80.71$; $df = 1,24$; $p < .01$), and there was no evidence of an interaction between these two task variables ($F < 1$; $df = 1,24$). Barbiturate-vs.-placebo showed a significant main effect on the RT ($F = 12.66$; $df = 1,18$; $p < .01$) and a small but significant interaction with the effect of stimulus degradation ($F = 6.65$; $df = 1,12$; $p < .05$). But the analysis of variance showed no significant evidence of an interaction between the effects of barbiturate and S-R compatibility ($F = 2.13$; $df = 1,12$; N.S.) or an interaction between the effects of barbiturate, stimulus degradation and S-R compatibility ($F = 1.66$; $df = 1,12$; N.S.).

Amphetamine-vs.-placebo, on the other hand, showed a significant interaction with the effect of S-R compatibility ($F = 11.52$; $df = 1,12$; $p < .01$), but no significant main effect ($F < 1$; $df = 1,18$). As Fig. 2 shows, there was no amphetamine effect in the compatible condition, but

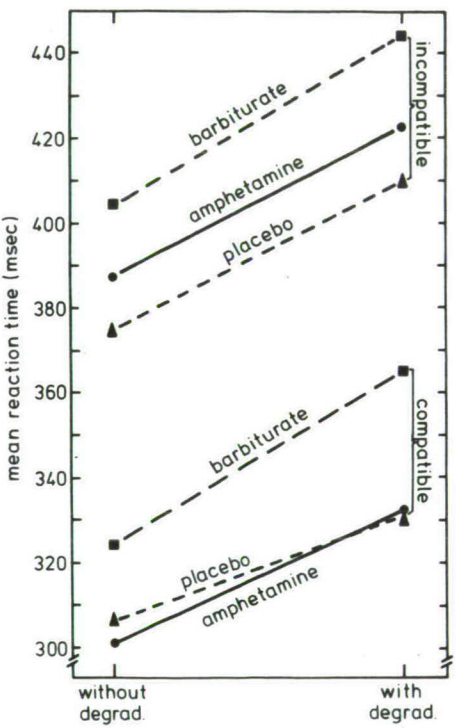

Fig. 2. Reaction time as a function of stimulus degradation, S-R compatibility and drug treatment.

in the incompatible condition amphetamine resulted in slower RT's. The other interactions between amphetamine and stimulus degradation ($F < 1$; $df = 1,12$) and between amphetamine, S-R compatibility and stimulus degradation ($F < 1$; $df = 1,12$) were not significant.

Movement times

As is evident from Fig. 3, there were no significant effects on the MT of stimulus degradation ($F = 2.47$; $df = 1,24$), S-R compatibility ($F < 1$; $df = 1,24$) and no interaction between these two variables ($F < 1$; $df = 1,24$). The effect of barbiturate vs. placebo was not significant ($F = 1.96$; $df = 1,18$) and neither were the first-order interactions of barbiturate with stimulus degradation ($F = 1.09$; $df = 1,12$) and S-R compatibility ($F = 1.49$; $df = 1,12$) or the second-order interaction of barbiturate with stimulus degradation and S-R compatibility ($F = 1.00$; $df = 1,12$).

Contrary to this, amphetamine had a significant main effect on the MT ($F = 4.72$; $df = 1,18$; $p < .05$); but again there were no significant interactions between amphetamine and stimulus degradation ($F < 1$; $df = 1,12$), amphetamine and S-R compatibility ($F < 1$; $df = 1,12$) or amphetamine, stimulus degradation and S-R compatibility ($F < 1$; $df = 1,12$).

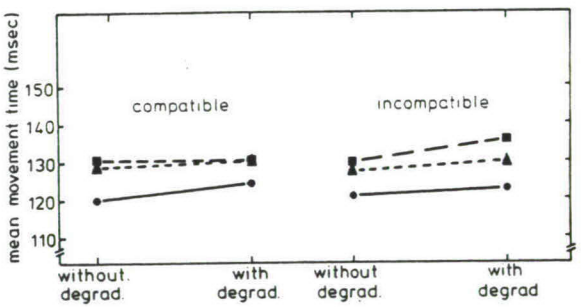

Fig. 3. Movement time as a function of stimulus degradation, S-R compatibility and drug treatment ■ – – – ■ = barbiturate ▲ ----- ▲ = placebo ● ——— ● = amphetamine

Discussion

The effects of task variables were consistent with previous findings. The effects of stimulus degradation and S-R compatibility on the RT were additive and neither of these variables had a significant effect on the movement time. Thus, the results confirm that visual encoding, response selection and response execution represent consecutive and independent stages. Moreover, as in the study by Tharp et al. (1974) on the effects of alcohol, this organisation of stages was unaffected by drugs. In this sense, the data provide additional evidence about the robustness of the structural organisation of the reaction process (see also Sanders, 1977).

Regarding the effects of amphetamine and barbiturate on individual stages, the data clearly show that these drugs have selective effects and that they affect different stages. For amphetamine, the most important effect was the decrease in the MT which indicates that amphetamine speeds up response execution. The data are more ambiguous about the influence of amphetamine on the other stages. The amphetamine x S-R compatibility interaction effect on the RT appears to indicate that for incompatible S-R relations, amphetamine has an inhibitory effect on response selection. But this interpretation is weakened by the failure to obtain a significant main effect of amphetamine on the RT, which would suggest that none of the stages preceding response execution are affected. Thus, although there is clear evidence that amphetamine speeds up response execution rather than encoding or response selection, the evidence with regard to an actual slowing down of the response selection process is more tentative. Barbiturate, unlike amphetamine, did not influence the MT. But there was a significant barbiturate effect on the RT, and this effect was additive with S-R compatibility and showed a small but significant interaction with the effect of stimulus degradation. Thus, the data indicate that barbiturate affects neither response selection nor response execution, but that it tends to slow down the stimulus encoding process.

How do these findings relate to the literature about the effects of these drugs in other types of performance tasks? Regarding the effects of amphetamine, the literature suggests that tasks which mainly involve motor processes are improved, whereas more cognitive tasks are not affected. There is evidence of improved athletic performance (Smith and Beecher, 1959), greater grip strength (Hurst et al., 1968) and greater endurance on a bicycle ergometer task (Williams and Thompson, 1973); but the review

paper by Weiss and Laties (1962) reports that amphetamine had no effect on arithmetic and problem solving tasks or on the Digit Symbol Substitution Test. Similarly, Quarton and Talland (1962) and Talland and Quarton (1965) found no evidence of an effect on the running memory span, and Kopell and Wittner (1968) found that amphetamine had no effect on the identification of forms which were superimposed by visual noise. Thus, the evidence from the literature is consistent with the present finding of selective improvement of the movement time. On the other hand, there is no real evidence in the literature of an inhibitory effect of amphetamine on response selection, and it seems prudent to suggest that this effect will need to be further tested.

With regard to the effects of low-dosage barbiturate treatment, the literature shows performance decrements in a great number of different tasks (e.g. Sanders and Bunt, 1971). However, because most of these tasks involve both stimulus and response processes, there is little evidence in the literature to corroborate the present indication that barbiturate has a selective effect on stimulus encoding. Nevertheless, there are some recent EEG studies by Otero and Mirsky (1976) and Hink et al. (1978) which indicate that barbiturate depresses the early but not the late components of the evoked potential.

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PAPER 3

EFFECTS OF AMPHETAMINE ON RESPONSE SELECTION AND RESPONSE EXECUTION PROCESSES IN CHOICE REACTION TASKS*

Summary

Two experiments were carried out to investigate the effect of an amphetamine derivative (phentermine HCl) on different stages in the reaction process. Experiment I showed that amphetamine shortened the reaction time, but this effect was additive with the effects of relative signal frequency and S-R compatibility, which suggests that the amphetamine effect on the reaction time cannot be attributed to a specific effect on the response selection stage. Experiment II showed that amphetamine shortened the movement time in a target-aiming task adapted from Fitts & Peterson (1964). This effect was greater for longer movements but independent of target width, which suggests that amphetamine specifically affects the motor processes involved in the execution of aiming responses but that the visual feedback processes during the movement were not affected by amphetamine. In addition, Experiment II showed an effect of amphetamine on the reaction time which was interpreted in terms of an amphetamine effect on the preparatory motor processes preceding the aiming response. These findings are consistent with findings in the literature suggesting effects of amphetamine in motor tasks rather than in cognitive and perceptual tasks.

* Report of the Institute for Perception TNO, Soesterberg, nr. IZF 1979-8

Introduction

This study is part of a project which aims at investigating the effects of stresses such as sleep deprivation or drugs on specific structural processes involved in task performance. Thus, given that a certain stress affects performance on a certain task, the problem from this point of view is to find which of the processes involved in carrying out that task are affected by that stress.

The experiments described below are specifically concerned with the effects of amphetamine. That amphetamine can bring about a real improvement in performance, is most clearly shown in the classic series of experiments by Payne & Hauty who used a multiple compensatory tracking task. When subjects performed this task continuously for four hours, amphetamine served to eliminate the marked decline in performance which usually occurs as a function of time-on-task (Payne & Hauty, 1954). This finding has since been supported by other positive effects of amphetamine on tracking performance. McKenzie (1965) and Schroeder et al. (1974) found that compensatory tracking was improved, and the studies by Evans et al. (1976) and Truijens et al. (1976) showed positive effects of amphetamine on pursuit tracking. Similarly, the literature also indicates that various types of muscular performance tasks can be improved by amphetamine. An extensive study by Smith & Beecher (1959) showed that amphetamine led to better performance in different types of athletic tasks such as swimming, track events and shot put. Other studies have shown improvement of grip strength (Hurst et al., 1968) and endurance on a bicycle ergometer task (Williams & Thompson, 1973). Furthermore, the evidence indicates that the positive influence of amphetamine cannot be easily dismissed as a mere motivational effect. In some of the Payne & Hauty studies it was found that the effect of amphetamine on tracking performance was independent of such motivational variables as knowledge of the task duration (Hauty & Payne, 1955) and feedback of performance scores (Payne & Hauty, 1956). Similarly, Smith & Beecher (1960) showed that the reward of a steak dinner for swimming performance did not cancel out the improvement brought about by amphetamine.

On the other hand, it appears that performance on more cognitive tasks seems to be unaffected by amphetamine. Some of the older studies reviewed by Weiss & Laties (1962) show no effect of amphetamine

on artihmetic and problem solving tasks and on the Digit Symbol Substitution Test. Also Quarton & Talland (1962) and Talland & Quarton (1965) found no evidence of an effect of amphetamine on the running memory span. The efficiency of visual encoding also does not seem to be affected. Kopell & Wittner (1968) found that amphetamine had no effect on the identification of forms which were superimposed by visual noise. Although the experiments by N.H. Mackworth (1950) and J.F. Mackworth (1965) may suggest an effect on visual encoding because it was shown that amphetamine can improve performance in a visual monitoring task, this effect can be attributed more readily to the fact that amphetamine increases the number of observing responses in such a situation (Weiner & Rosse, 1962).

In summary, the literature suggests that amphetamine improves muscular performance and performance on tracking tasks, but has no effect on the efficiency of cognitive tasks or visual encoding. Because performance on tracking tasks as well as muscular performance tasks depends to a considerable extent on the efficiency of motor processes, this suggests that amphetamine improves these motor processes. At the same time it should be noted that conclusions based on these different studies are somewhat speculative. Firstly, because of the use of different drug dosages; and secondly, because any interpretation of different effects of a drug on different tasks is inconclusive if the processes involved in carrying out these different tasks differ in more than one respect. Thus, to address the problem of getting more conclusive data about the effects of drugs on specific structural processes, a different type of approach is needed.

The strategy for the present research was derived from Summerfield (1966) and Sanders & Bunt (1971). In principle this means looking for selective drug effects with regard to specific task conditions or components of a task. Choice reaction tasks are suitable for this purpose, because they involve perceptual, decision and motor processes which can be identified and manipulated. According to the logic of Sternberg's additive factor method, it can be inferred that two or more task variables affect independent processing stages if they show additive contributions to the mean RT, while an interaction between the effects of different task variables can be assumed to indicate that these variables affect the same processing stage. Ap-

plication of this method can lead to a picture of the consecutive stages which make up the reaction process. Thus, it has been consistently shown that the effects of visual stimulus degradation and S-R compatibility are additive (Sternberg, 1969; Schwartz et al., 1977; Sanders, 1979), and it can be inferred that these two variables affect consecutive processing stages which may be referred to as encoding and response selection. Furthermore, in an extension of the additive factor method, Frowein & Sanders (1978) used the reaction time (RT) and movement time (MT) as consecutive response measures, and found that stimulus degradation and S-R compatibility had additive effects on the RT, but that the MT was not affected by these variables. Thus, they concluded that the MT represents a separate response execution stage which is independent of visual encoding and response selection.

In a subsequent experiment, Frowein (1979) used essentially the same task to investigate which of these stages are affected by an amphetamine and which stages are affected by a barbiturate. With regard to the effects of amphetamine, the data showed a significant shortening of the MT but no main effect of the RT, which would suggest that amphetamine speeds up response execution but has no effect on the previous stages which make up the RT. However, although amphetamine did not show a significant main effect on the RT, there was an interaction between the effects of amphetamine and S-R compatibility on the RT. Amphetamine did not differ from placebo in the compatible condition, but in the incompatible condition amphetamine resulted in longer RT's. Thus, it would appear that, while amphetamine speeds up response execution, it slows down response selection when S-R compatibility is low. On the other hand, the failure to obtain a significant effect of amphetamine on the RT would go against this conclusion because an effect on response selection should also result in an effect on the RT. Because of this discrepancy, and because there is no other evidence in the literature to indicate that amphetamine impairs or slows down response selection, it was felt that the effect of amphetamine on response selection needed further testing. The first experiment served this purpose, while the second experiment was mainly concerned with the effect of amphetamine on response execution. In addition, both these experiments served to investigate the effect of time-on-task and the effect of drug dosage.

EXPERIMENT I Effects of amphetamine, S-R compatibility and relative signal frequency on choice reaction time

The purpose of this experiment was to provide a further test of the hypothesis that amphetamine slows down response selection. Firstly, the relationship between the effects of amphetamine and S-R compatibility was again investigated in a CRT-task. Secondly, an additional task variable, i.e. relative signal frequency, was introduced because it has been repeatedly shown that there is an interaction between the effects of relative signal frequency and S-R compatibility (e.g. Sanders, 1970; Hawkins et al., 1973; Stanovitch & Pachella, 1977), which in accordance with the additive factor logic means that they must affect a common processing stage. Furthermore, because there is no evidence that S-R compatibility affects other stages apart from response selection (Sanders, 1977), it may be inferred that relative signal frequency also affects the response selection stage. Thus, if amphetamine affects response selection this should be evident not only from an interaction between the effects of amphetamine and S-R compatibility on the RT but also from an interaction between amphetamine and relative signal frequency. Moreover, there should be a second-order interaction between the effects of amphetamine, S-R compatibility and signal frequency on the RT.

Method

Subjects. The subjects were 24 healthy male students with an age range from 17 to 30 years. They were paid Hfl. 60,-- a day for participation in the experiment; a daily bonus of approx. Hfl. 5,-- to Hfl. 10,-- was awarded on the basis of their performance during the experimental task.

Drug treatment. The drug conditions were two dosages of an amphetamine derivative (i.e. 20 and 40 mg phentermine HCL) and a placebo. The drug treatment was always administered by means of a suppository to ensure a relatively constant plasma concentration during the post-treatment experimental sessions. Allocation of drug treatment was double-blind, in the sense that neither the experimenter nor the subjects knew which drug condition was administered, but they both knew which drugs were used in the experiment.

Experimental task and apparatus. The subject was seated at a sloping desk in a sound-attenuating room. The display, which was mounted on the desk top, is diagrammatically presented in Fig. 1. The circles a, b, c and d represent the stimulus lights and the crosses 1, 2, 3 and 4 represent the response keys. The middle and index fingers of the left hand were positioned on response keys 1 and 2 respectively, and the right index and middle finger were resting respectively on response keys 3 and 4. In the compatible situation the correct stimulus-response relations were a-1, b-2, c-3 and d-4, while the mirror image of this situation represented the correct stimulus-response re-

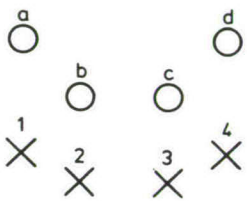

Fig. 1. Task situation in Experiment I.

lations in the incompatible condition, i.e. a-4, b-3, c-2, d-1. The stimulus frequencies were .55, .15, .15 and .15. Light c was the most probable stimulus (.55) in the compatible condition, and light b was the most probable stimulus in the incompatible condition. This means that in both the compatible and the incompatible condition, the most frequent correct response was to press response key 3 (the right index finger). Subjects were informed about this frequency distribution before the experiment was started.

The preprogrammed stimulus presentation was carried out by the PSARP system (van Doorne and Sanders, 1968). The stimulus duration was always 200 msec and the stimuli were presented at a constant rate of one every four seconds.

Design and procedure. The independent variables were drug treatment, S-R compatibility and relative signal frequency. Drug treatment was varied between matched groups of 8 subjects each, and compatibility was varied within subjects but between experimental sessions in a

counter-balanced order. Each experimental session lasted 60 minutes, and time-on-task effects were assessed by partitioning the experimental sessions into consecutive 10-min periods, which contained 150 trials each.

The program consisted of one training and one experimental day. On the morning of the training day, subjects received a medical examination including blood and urine test. After that they received four 10-min practice sessions: two sessions with the compatible condition and two sessions with the incompatible condition. The interval between practice sessions was 30 minutes. The RT's obtained during the training day were used to form three matched groups of eight subjects for allocation of drug treatment during the experimental day. This was done by forming sets of three subjects with similar performance level and distributing the three drug conditions among the three subjects in each set.

Table I. Time-schedule of program during experimental day.

Time	First Subject	Time	Second Subject
09.00-09.10	pre-treatment session 1		
	rest	09.10-09.20	pre-treatment session 1
09.20-09.30	pre-treatment session 2		rest
		09.30-10.00	pre-treatment session 2
10.00	treatment administration		
11.15-11.20	practice session 1	11.15	treatment administration
11.30-12.30	experimental session 1		
		12.30-12.35	practice session 1
		12.45-13.45	experimental session 1
13.45-13.50	practice session 2		
14.00-15.00	experimental session 2		
		15.00-15.05	practice session 2
		15.15-16.15	experimental session 2

On each experimental day two subjects were alternately tested. The time-schedule of the program is presented in Table I. Before drug treatment, there were two 10-minute sessions, one for the compatible task and one for the incompatible task. For each of the matched groups, half the subjects carried out the compatible task first, whereas the other half carried out the incompatible task first. Experimental sessions started $1\frac{1}{2}$ hours after treatment and finished 5 hours after treatment. Under these conditions it can be assumed that

plasma concentration of the drugs remains relatively stable during post-treatment performance (Vree, 1973). For each of the three matched groups, half of the subjects received the compatible condition in the first session and the incompatible condition in the second session, while for the other half the reverse order applied. To limit the effects of switching from one condition to another, each experimental session was preceded by a 5-minute practice session. The distribution of stimuli across trials was randomly determined with the limitation that the probability differences (.55, .15, .15, .15) between stimuli applied for each of the consecutive 10-minute periods within a 60-minute experimental session.

Results and discussion

Because the mean RT's obtained during the pre-treatment sessions did not show a difference between groups ($F < 1$; d.f. = 2,21), it was assumed that matchings were adequate. Thus, drug treatment was analysed as a within-subjects variable with each set of three matched subjects being treated as one subject. The analysis of variance on the error-free RT's, obtained during the experimental sessions, showed significant effects of relative signal frequency ($F = 220$; d.f. = 1,7; $p < .01$); S-R compatibility ($F = 94.4$; d.f. = 1,7; $p < .01$) and the interaction between these two variables ($F = 62.6$; d.f. = 1,7; $p < .01$). The effect of drug treatment was also significant ($F = 3.97$; d.f. = 2,14; $p < .05$) but as Fig. 2 shows, there was no noticeable difference between the two dosages of the amphetamine.

With regard to the relationship between the effect of amphetamine and the effect of S-R compatibility, the data failed to replicate the interaction found in the aforementioned study (Frowein, 1979). Although Fig. 2 shows a greater effect of amphetamine in the compatible (C_1) than in the incompatible (C_2) condition the interaction did not approach significance ($F < 1$; d.f. = 2,14). Similarly, there was no trace of an interaction between drug treatment and relative signal frequency ($F < 1$; d.f. = 2,14) or between drug treatment, relative signal frequency and S-R compatibility (F 1; d.f. = 2,14). Thus, assuming that both S-R compatibility and relative signal frequency affect the response selection stage of the reaction process, it must be concluded that these data failed to support the hypothesis that amphetamine has an effect on this response

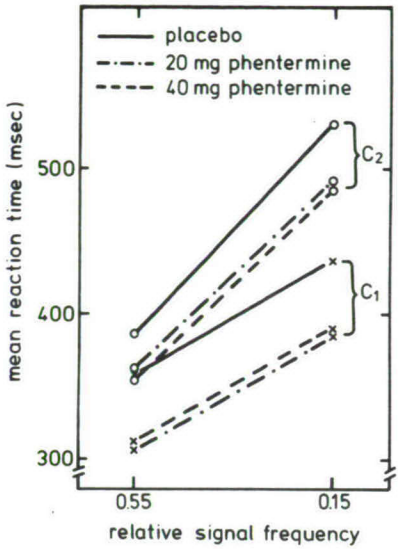

Fig. 2. Reaction time as a function of drug treatment, S-R compatibility (C_1-C_2) and relative signal frequency.

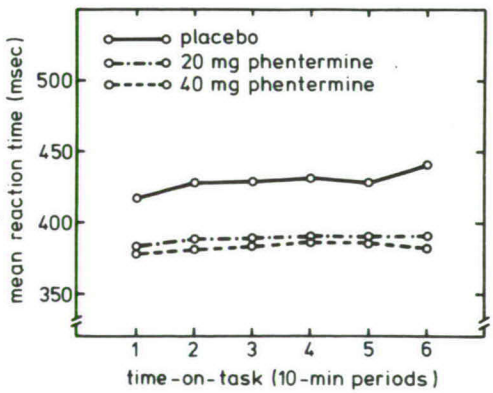

Fig. 3. Reaction time as a function of drug treatment and time-on-task.

selection stage. This conclusion received further support from an additional analysis of the RT-variances, which provides a stronger test of the independence of factors (Sternberg, 1969; Taylor, 1976). Although there were significant effects of drug treatment ($F = 4.41$; d.f. = 2,12; $p < .05$) and S-R compatibility ($F = 29.04$; d.f. = 2.12; $p < .05$), the interaction between these two variables did not approach significance ($F = 1.03$; d.f. = 2,12). Furthermore, there was no evidence of an interaction between the effects of drug treatment and relative signal frequency ($F < 1$; d.f. = 2,12).

With regard to the effects of time-on-task, shown in Fig. 3, there was a small but significant main effect ($F = 3.64$; d.f. = 3.35; $p < .01$), but the interaction with drug treatment was not significant ($F < 1$; d.f. = 10,70). Thus, the amphetamine effect in this experiment was not dependent on the effect of time-on-task.

Percentages of incorrect reactions are presented in Table II below. The analysis of variance showed significant main effects of S-R compatibility ($F = 11.5$; d.f. = 1,7; $p < .05$) and relative signal frequency ($F = 9.6$; d.f. = 1,7; $p < .05$), but there were no significant effects of either drug treatment ($F < 1$; d.f. = 2,14), time-on-task ($F = 2.02$; d.f. = 5,35) or any of the interactions between the different variables.

Table II. Percentages of incorrect reactions as a function of drug treatment, relative signal frequency and S-R compatibility (C_1 = High Comp.; C_2 = Low Comp.).

COMP./REL. SIG. FREQ.	DRUG TREATMENT		
	Placebo	20 mg. Phent.	40 mg. Phent.
$C_1/.55$	.7	.6	.6
$C_1/.15$	2.6	2.2	2.5
$C_2/.55$	1.2	1.3	1.1
$C_2/.15$	5.2	6.5	5.2

EXPERIMENT II Effects of amphetamine on reaction time and movement time, under different conditions of movement amplitude and target width

As mentioned in the Introduction, it had been previously found that amphetamine speeded up the movement time (Frowein, 1979), and this was interpreted as an effect on the response execution process which may be assumed to occur subsequent to the processing stages of encoding and response selection. The movement times in this experiment were always well below 200 msec, which means that there was not enough time for visual feedback to play a role in the aiming of the movement. Because other modes of feedback are not sufficient for feedback control of a target aiming response of this sort (e.g. Klapp, 1975), it follows that response execution was not under feedback control and must have been programmed prior to initiation. The purpose of the present experiment was to investigate effects of amphetamine in a situation where response execution involves larger and more complex movements which may be assumed to be at least partially controlled by feedback. The experimental task was a two-choice task derived from Fitts & Peterson (1964) with two levels of target width (W) and two levels of movement amplitude (A) as the main task variables.

Method

Subjects. Subjects were twelve healthy male students. They were paid Hfl. 60,-- a day for participating in the experiment, and an extra bonus of approx. Hfl. 5,-- to Hfl. 10,-- a day was awarded on the basis of their performance during the reaction tasks.

Drug treatment. The treatment conditions were the same as in Experiment I, i.e. placebo, 20 mg phentermine HCL and 40 mg phentermine HCL. Allocation of drug treatment was double blind in the sense that neither the experimenter nor the subjects knew which drug condition was administered on any particular day, but they both knew which drugs were used in the experiment. As in Experiment I the subjects administered the drug treatment themselves by means of a suppository.

Experimental task and apparatus. Fig. 4 presents a schematic representation of the experimental set-up. The subject was seated at a

sloping desk with in his preferred hand, a light-weight stylus which rested on the small metal starting plate. His task was to fixate the red warning light (WL) and to hit the appropriate metal target plate as quickly as possible when one of the two white reaction lights (RL) came on. For each trial, the stimulus sequence was started with the red warning light which lasted 1000 msec and which was immediately followed by a 200 msec reaction light. The cycle duration of each trial (i.e. the interval between the onsets of consecutive warning

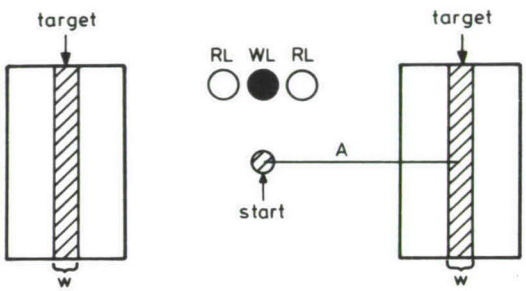

Fig. 4. Task situation in Experiment II.

signals) was 4000 msec. The pre-programmed signal presentation and the registration of responses was performed by the PSARP system (van Doorne and Sanders, 1968). The reaction time (RT) was defined as the interval between the onset of the reaction signal and the release from the starting plate, and the movement time (MT) was defined as the interval between the release of the starting plate and the touching of either one of the two target plates or one of the undershoot or overshoot plates which were mounted adjacent to the target plates. The plates were 10 cm long and the width of the undershoot and overshoot plates was always 3 cm. Subjects were instructed that movements should be made without hesitation, and that movements in the wrong direction should never be corrected during the movement. The task variables were movement aplitude (A) and target width (W). Movement amplitude was either 10 cm (A_1) or 30 cm (A_2), as measured by the distance between the midpoint of the starting plate and the midline of the target plate, and target width was either 2.4 cm (W_1) or 0.8 (W_2). Thus there were four task conditions, i.e. large target width-

small amplitude (W_1A_1), large target width-large amplitude (W_1A_2), small target width-small amplitude (W_2A_1) and small target width-large amplitude (W_2A_2).

Procedure and design. Drug treatment was varied between experimental days, while movement amplitude and target width were varied between sessions but within days. A completely within-subjects design was used in this experiment, whereas in Experiment I, drug treatment was varied between matched groups. The main reasons for this change were experimental expediency and the problem of matching subjects on a number of different task conditions. It was felt that a within-subjects design was justified, because with an interval of one week between drug treatments, there should be no carry-over of drug effects, and because subjects were well-trained prior to the experimental session no large practice effects were to be expected (In fact, the data did not show any evidence of practice effects between consecutive experimental days). The order of drug treatments was balanced in the manner of a Latin square; the order of target widths was balanced within each order of treatment conditions, and the order of movement amplitudes was balanced within each order of target widths. For each subject, the program consisted of one training day and three experimental days. On the training day, the subject had a medical examination including blood and urine tests, and after that he carried out the same sequence of task conditions as during the experimental days. During the training day, the subject received feedback about the total times (RT + MT) and about the accuracy of his performance. Subjects were told that, during the experimental days, a bonus would be computed on the basis of their mean total time for correct responses, but that no bonus would be paid for sessions with more than 10% errors (which included incorrect decisions, overshoots and undershoots). During the experimental days, when drug treatments were administered, no further feedback about performance was given. On each experimental day, two subjects were run alternately, so that one subject carried out one of the task conditions while the other subject was resting. The first subject received his drug treatment at 9.00 a.m. and the first experimental session was started at 10.30 a.m., while the second subject received his drug treatment at 9.35 a.m. and started the first session at 11.05 a.m. Each task condition was carried out for a 30-min. session, and there was a 35-min. rest-period between sessions.

Method of analysis and normalization of movement times. There were 450 trials in each 30-min. session, and to assess the effects of time-on-task the data of each session were divided up into 3 periods of 10 minutes and 150 trials. In the analysis only those trials were used which did not involve a decision error (i.e. a movement in the wrong direction). Decision errors amounted to less than 2% of the total number of trials and were not separately analyzed.

Reaction times and movement times were separately analyzed. With regard to the movement times, it was necessary to apply an additional analysis whereby the mean movement times for each individual session were corrected for shifts in the trade-off between the speed and accuracy of movement. An initial inspection of the movement times and the percentages of overshoot and undershoot errors for each subject had shown some large shifts in the speed-accuracy trade-off which could not be attributed to practice or drug treatment. To cancel out these speed-accuracy shifts, the MT's were "normalized". To achieve this, the individual speed-accuracy trade-off functions were determined post hoc for each of the four task conditions. All subjects were called up for an additional day of experimentation, and during that day each of the four task conditions was carried out under three levels of the speed-accuracy trade-off which was manipublated by means of deadlines, i.e. if the subject exceeded the deadline he received a loud auditory tone via a loudspeaker. Subjects were instructed that they should never make anticipations (which might result in movements in the wrong direction), and that not more than 20% of their responses should exceed the deadline. Deadlines were individually determined on the basis of performance during the placebo condition. For each of the four task conditions, the longest deadline (D_1) equalled the mean total time ($\bar{X}$ RT + $\bar{X}$ MT), and the two faster deadlines (D_2 and D_3) were determined by deducting respectively 15% and 30% of the $\bar{X}$ MT from D_1. Each deadline condition was carried out for a 10-min. period, and the three deadline conditions for one task condition were presented one after another during a 30-min. session. Subjects were alternately run, and there was always a 35min. rest-period between task conditions. The order of task conditions was the same as on previous days, and the sequence of deadline conditions was partially counterbalanced within the order of task conditions half the subjects received the deadlines in the order

D_1-D_2-D_3, while the other half received them in the reverse order. The procedure for determination of trade-off functions was adapted from Pew (1969) who found that in a variety of reaction time tasks, the trade-off function could be described by a linear relation between the RT and the log odds (number of correct responses/number of errors). With regard to the present task, the mean MT was plotted against the log odds for movement errors (i.e. the number of correct target hits divided by the number of overshoots and undershoots) for each of the three deadline conditions. The data conformed to those of Pew in that linear relationships were found between the MT and log odds for each of the four task conditions. Given this linearity, it was possible to "normalize" the MT's on the basis of the individual trade-off functions obtained for each of the four task conditions. Assuming that any shifts in the trade-off criteria, would have followed the slopes of these individual trade-off functions, it follows that the MT at any value of the log odds could be predicted from the individual trade-off functions. In other words, to correct the MT's for shifts in the speed-accuracy criterion, one can compute the predicted MT's at a constant value of log odds. For the present experiment, the normalized MT's were the predicted MT's at log odds = 1.00.

Results and discussion

Reaction times. Effects of movement amplitude (A) and target width (W) are shown in Fig. 5. The analysis of variance showed a small but clearly significant effect of movement amplitude ($F = 9.17$; d.f. = 1,24; $p < .01$), but there was no significant effect of target width ($F < 1$; d.f. = 1,24) or of the interaction between target width and movement amplitude ($F = 2.40$; d.f. = 1,24). This is consistent with previous findings. Fitts and Peterson's data showed significant effects on the RT of movement amplitude, while target width had no effect. Klapp (1975) and Siegel (1977) carried out similar experiments with a large range of target widths and movement amplitudes, and for values of width and amplitude similar to those used in the present experiment their data also show longer RT's for longer movements but only slight or no effects of target width. This may be taken as evidence that response programming was longer for longer movements but unaffected by target width. As noted by Hayes & Marteniuk (1976) in their discussion of the Fitts & Peterson study, it is likely that the

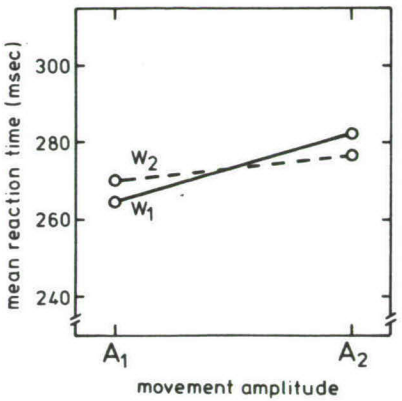

Fig. 5. Reaction time as a function of target width (W_1-W_2) and movement amplitude (A_1-A_2).

first part of the movement in the direction of the target was programmed but that the second part of the movement, which involves the actual touching the target, was under feedback control.

Fig. 6 shows the effects of drugs treatment and time-on-task for each of the four task conditions. The main effect of drug treatment was significant ($F = 4.45$; d.f. = 2,18; $p < .05$), but there was no consistent difference between the two amphetamine dosages. Of special interest is the relationship between the effects of drug treatment and movement amplitude. If movement amplitude affects response programming during the reaction time, it follows that an effect of amphetamine on response programming should be evident from an interaction between drug treatment and movement amplitude in their respective effects on the RT. Unfortunately, the data are not quite conclusive on this point. Although Fig. 6 shows larger amphetamine effects for the longer movements (particularly for the small target width), the analysis of variance showed no significant interactions for drug treatment x movement amplitude ($F = 1.12$; d.f. = 2,12), drug treatment x target width ($F = 1.08$; d.f. = 2,12) or drug treatment x movement amplitude x target width ($F = 2.54$; d.f. = 2,12).

Regarding the effects of time-on-task, there were small but significant effects ($F = 8.21$; d.f. = 2,12; $p < .01$), and there was a significant time-on-task x drug treatment interaction ($F = 2.88$; d.f.

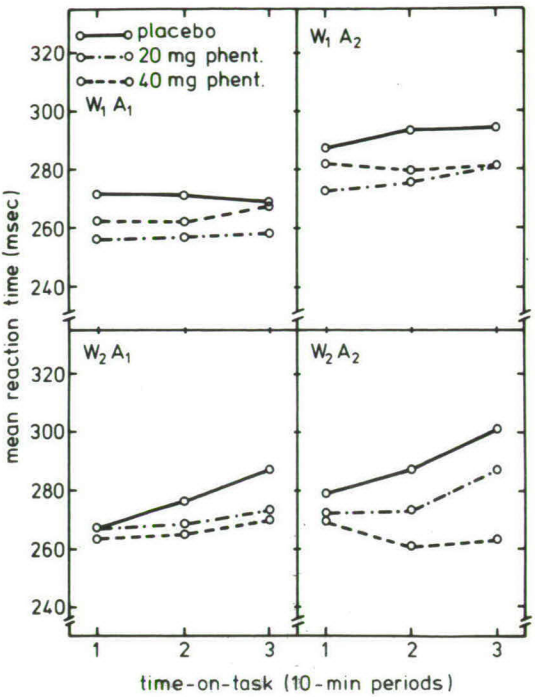

Fig. 6. Reaction time as a function of drug treatment and time-on-task for each of the four task conditions.

= 4,36; $p < .05$), indicating larger amphetamine effects at the end of the 30-in. sessions. Furthermore, Fig. 6 suggests larger effects of amphetamine and of time-on-task in the W_2-conditions than in the W_1-conditions, but the analysis of variance did not show significance for either the first-order interaction between time-on-task and target width ($F = 2.34$; d.f. = 2,48) or the second-order interaction between time-on-task, drug treatment and target width ($F = 2.60$; d.f. = 4,24).

Movement times. Figures 7 and 8 show the normalized MT's, which were derived from the individual trade-off functions (see Method section). There were large main effects of target width ($F = 327.86$; d.f. = 1,24; $p < .01$) and movement amplitude ($F = 116.82$; d.f. = 1,24; $p<.01$) but the relationship between these two variables appears to

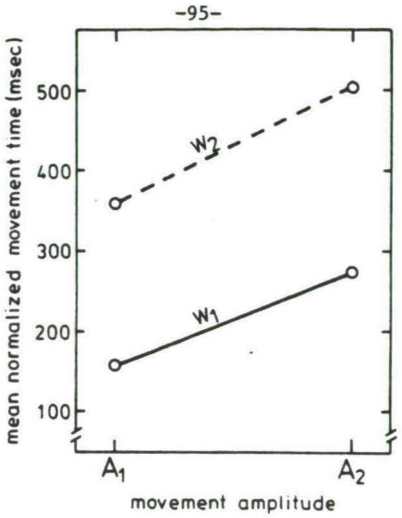

Fig. 7. Normalized movement time as a function of target width (W_1-W_2) and movement amplitude (A_1-A_2).

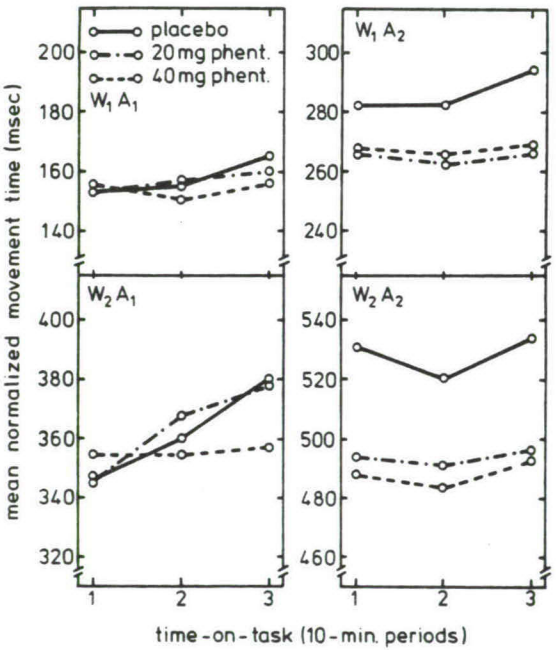

Fig. 8. Normalized movement time as a function of drug treatment and time-on-task for each of the four task conditions.

be additive ($F = 1.17$; d.f. = 1,24), which suggests that target width and movement amplitude affected different processes in this experiment. This is consistent with the effects of these variables on the RT which indicated that motor programming takes longer for longer movements but is unaffected by target width. Thus, a plausible interpretation of the independent effects of movement amplitude and target width on the MT is that movement amplitude affected the initial part of the movement which is programmed, whereas target width affects the subsequent part which is feedback-controlled.

The effects of drug treatment, as shown in Fig. 8, can also be accounted for within this context. The analysis of variance showed a main effect of drug treatment ($F = 3.81$; d.f. = 2,18; $p < .05$), and an interaction of drug treatment with movement amplitude ($F = 5.14$; d.f. = 2,12, $p < .05$), while the relationship between drug treatment and target width was additive ($F < 1$; d.f. = 2,12). Thus, it appears that amphetamine had the effect of shortening the programmed part of the movement, but that the part which is feedback-controlled was unaffected.

Regarding the effects of time-on-task, Fig. 8 indicates that the MT increased as a function of time-on-task in the A_1-conditions but not in the A_2-conditions. This was confirmed by the analysis of variance which showed a significant time-on-task x amplitude interaction ($F = 3.87$; d.f. = 2,48; $p < .05$), although the main effect of time-on-task did not reach significance ($F = 3.32$; d.f. = 2,12). Furthermore, there was no significant interaction between time-on-task and drug treatment ($F = 2.10$; d.f. = 4,36), and none of the other first- or second-order interactions approached significance.

Concluding comments

To sum up, the following conclusions can be made regarding the effects of amphetamine on specific response processes. Firstly, the effect of amphetamine on the MT indicates that amphetamine speeds up the response execution process. This is consistent with a trend in the literature suggesting that amphetamine improves performance when motor processes play an important role in carrying out the task. Secondly, the relationship between this effect and the effect of the task variables on the MT suggests that amphetamine speeds up only the programmed part of the movement and has no effect on the efficiency of feedback-controlled movement. Thirdly, the data showed no evidence

of an amphetamine effect on response selection, as had been suggested by previous results (Frowein, 1979). This illustrates the need to replicate drug effects before definite conclusions can be arrived at; particularly when the effects are ambiguous and unsupported by the literature.

Apart from this, there are also some loose ends to be dealt with. Frowein (1979) found that amphetamine speeded up the MT but had no effect on the RT, while Experiment II of this study showed an effect on the RT as well as the MT. Thus, the Frowein (1979) study indicates amphetamine only improves response execution, whereas Experiment II suggests that amphetamine also improves some other process or processes occurring during the reaction time and prior to response execution. On this point, the results of Experiment II are supported by those obtained in Experiment I. Although the RT in Experiment I also includes the response execution stage, only a short buttonpressing movement was required and it does not seem plausible to explain the rather large amphetamine effect solely in terms of an effect on this movement. A possible explanation for this discrepancy may be derived from a look at the different tasks used in these three experiments. Although all three involved a visual choice task, the task used by Frowein (1979) required a forward movement on all trials so that some preparatory process with regard to the direction of movement could occur before the reaction signal appeared. Contrary to this, no such preparation could occur in the present experiments where the reaction signal indicated which finger had to be used (Experiment I) or in which direction the movement had to be made (Experiment II). Thus, to account for the discrepancy between these experiments and the previous study, it could be postulated that amphetamine affects some preparatory motor process occurring before the response execution stage. This process could be thought of, for instance, as a presetting of the response muscles, i.e. what Sanders (1979) called "intensive preparation". Although these preparatory motor processes are themselves not yet well-understood and an explanation along these lines is necessarily speculative, it may be considered independently of the issue as to whether or not amphetamine has an effect on response programming (see Experiment II), because the experiments by Klapp (1977) and Klapp et al. (1978) indicate that response programming does not involve specific muscles, but should be regarded as an abstract timing process which can be applied to any appropriate neural network.

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PAPER 3A

MOVEMENT TIME AND THE SPEED-ACCURACY TRADE-OFF FUNCTION*

Summary

It was shown by Pew (1969) that the speed-accuracy trade-off function in a choice reaction task is described by a linear relationship between RT and the logarithm of the odds (number of correct responses/number of incorrect responses). The present experiment investigated if a similar trade-off relationship exists with respect to the speed and accuracy of movement. The task was a two-choice target-aiming task adapted from Fitts and Peterson (1964). Independent task variables were target width (2.4 cm and 0.8 cm) and movement amplitude (10 cm and 30 cm). A deadline procedure was used to induce the necessary shifts in the speed-accuracy trade-off criterion, and movement errors were defined as hits next to instead of on the target. The results are consistent with Pew (1969) in that a linear relationship was observed between MT and the log odds (number of target hits/number of movement errors).

* A more elaborate version will be published in the Bulletin of the Psychonomic Society with A.F. Sanders as co-author.

Introduction

Several investigators have studied the relationship between speed and accuracy in choice reaction tasks. The speed-accuracy in these studies share a common characteristic. A review by Pew (1969) shows that under a variety of task conditions, a linear relationship was observed between the log odds (i.e. the number of correct responses/number of errors) and reaction time (RT), although there were differences in slope and intercept between experimental tasks and between subjects.

Knowledge of the speed-accuracy trade-off function can be useful when uncontrolled shifts in the trade-off criterion contaminates the investigation of experimental variables in their effect on RT. To circumvent this problem, reaction time measures may be adjusted on the basis of the speed-accuracy trade-off functions obtained in similar task conditions with the same subjects. Examples of this approach are the experiments by Wagenaar and Stakenburg (1975) and Frowein and Sanders (1978).

Unwanted variations in the speed-accuracy may also interfere with the investigation of experimental variables in their effect on movement time (MT). This occurred for instance in a previous experiment (Frowein, 1979) in which the target-pointing task of Fitts and Peterson (1964) was used to investigate the influence of an amphetamine derivative. Although the data suggested that this stimulus drug improved motor performance, its effect on the speed as well as the accuracy was unstable due to unsystematic variations in the speed-accuracy trade-off criterion. Thus the question arose if MT's (like RT's) could be adjusted on the basis of the speed-accuracy trade-off function. In particular, if linear trade-off functions could be established between MT and a measure of movement accuracy, the observed MT's could be adjusted to cancel out the influence of speed-accuracy trade-off shifts.

For this purpose, a deadline experiment was carried out with the same Fitts and Peterson task and the same subjects as had been used in the amphetamine study (Frowein, 1979)

Method

Subjects

Subjects were twelve healthy male students, who had all received extensive practice with the Fitts and Peterson task during a previous experiment. They were paid Hfl. 60,- for participating in the experiment, and an extra bonus of approximately Hfl. 5,- to Hfl. 10,- on the basis of their performance.

Experimental task and apparatus

Figure 1 presents a schematic representation of the experimental set-up. The subject was seated at a sloping desk with in his preferred hand, a light-weight stylus which rested on the small metal starting plate. His task was to fixate the red warning light (WL) and to hit the appropriate metal target plate as quickly as possible when one of the two white reaction lights (RL) came on. For each trial, the stimulus sequence was started with the red warning light which lasted 1000 msec and which was immediately followed by a 200 msec reaction light. The cycle duration of each trial (i.e. the interval between the onsets of consecutive warning

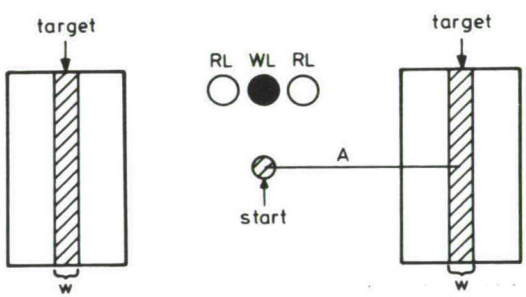

Fig. 1. Schematic representation of task situation.

signals was 4000 msec. The pre-programmed signal presentation and the registration of responses was performed by the PSARP system (Van Doorne and Sanders, 1968). For purposes of analysis the reaction time (RT) was defined as the interval between the onset of the reaction signal and the release

from the starting plate, and the movement time (MT) was defined as the interval between the release of the starting plate and the touching of either one of the two target plates or one of the undershoot or overshoot plates which were mounted adjacent to the target plates. Errors were categorized into two classes: movements in the wrong direction were classified as decision errors and hits on the overshoot or undershoot plates were classified as movement errors.

The task variables were movement amplitude (A) and target width (W). Movement amplitude was either 10 cm (A_1) or 30 cm (A_2), as measured by the distance between the midpoint of the starting plate and the midline of the target plate, and target width was either 2.4 cm (W_1 or 0.8 cm (W_2). Thus, there were four task conditions W_1A_1, W_1A_2, W_2A_1 and W_2A_2.

A deadline procedure was used to bring about the necessary shifts in the speed-accuracy trade-off criterion, i.e. if a response exceeded, the subject received a loud auditory signal via a loudspeaker. There were three levels of deadline for each of the four task conditions, and these were determined individually on the basis of a subject's performance during the previous experiment (Frowein, 1979). The longest deadline (D_1) equalled the mean total time (RT + MT), and the two faster deadlinde (D_2 and D_3) were determined by deducting respectively 15% and 30% of the mean MT from D_1. Each deadline condition was carried out for a 10-min. period, and the three deadline conditions for one task condition were presented one after another during a 30-min. session. Subjects were alternately run, and there was always a 35-min. rest-period between task conditions.

The sequences of task and deadline conditions were counterbalanced with the sequences of movement amplitudes counterbalanced within each sequence of target widths, and the sequences of deadline conditions counterbalanced within each sequence of movement amplitudes. With respect to the deadline conditions, there were only two sequences: from long to short (D_1-D_2-D_3) and from short to long (D_3-D_2-D_1).

Subjects were instructed to avoid making movements in the wrong direction, and not to make anticipations (which might also result in movememts in the wrong direction). They were told that their bonus would be computed on the basis of the number of correct movements made within the deadline, but that they would not get any bonus if more than 20% of their responses should exceed the deadline.

Results

Reaction times and decision errors

Because the main purpose of the experiment was to determine the relationship between the speed and accuracy of movement, subjects were specifically instructed to avoid incorrect decisions (movement in the wrong direction). Also, it was easy not to make decision errors because there were only two response alternatives and S-R compatibility was high. Thus, when looking at the individual data, it was not surprising to find many cases where no decision errors were made during a particular task condition, which means that it was not feasible to compute the odds (number of correct responses/number of incorrect responses) and plot a trade-off function in the manner suggested by Pew (1969). Nevertheless, as suggested by Table I, there was some tendency for shorter deadlines to bring about more decision errors (particularly in the W_1-conditions), but the accompanying decrease in reaction time was only slight.

Table I. Mean reaction times (msec) and percentages of decision errors (in brackets).

Conditions	Deadlines		
	D_1	D_2	D_3
W_1A_1	229 (3.3 %)	226 (5.4 %)	223 (11.3%)
W_2A_1	246 (0.3 %)	245 (1.7 %)	247 (1.4 %)
W_1A_2	257 (1.0 %)	253 (1.6 %)	247 (4.1 %)
W_2A_2	264 (0.3 %)	267 (0.7 %)	259 (2.4 %)
$\sum \bar{X}$	249 (1.2 %)	248 (2.4 %)	244 (4.8 %)

Movement times and movement errors

To exclude the possible influence of decision errors on movement, only correct decision trials were included, for the analysis of movement times (MT's) and movement errors (undershoots and overshoots). These were computed individually for each deadline and task condition. Because each sub-

ject made at least one movement error in each of these conditions, it was possible to compute the individual log odds (number of target hits/number of movement errors) and plot these against MT to obtain for each subject a set of trade-off function analogous to trade-off functions described by Pew (1969) for RT.

The group data are pictured in Fig. 2, which clearly shows a linear relationship between the log odds and MT. Also the differences in slope between the different task conditions, suggest that, in the case of smaller target widths and greater movement amplitudes, a relatively greater decrease in MT results in a similar decrease in accuracy (log odds).

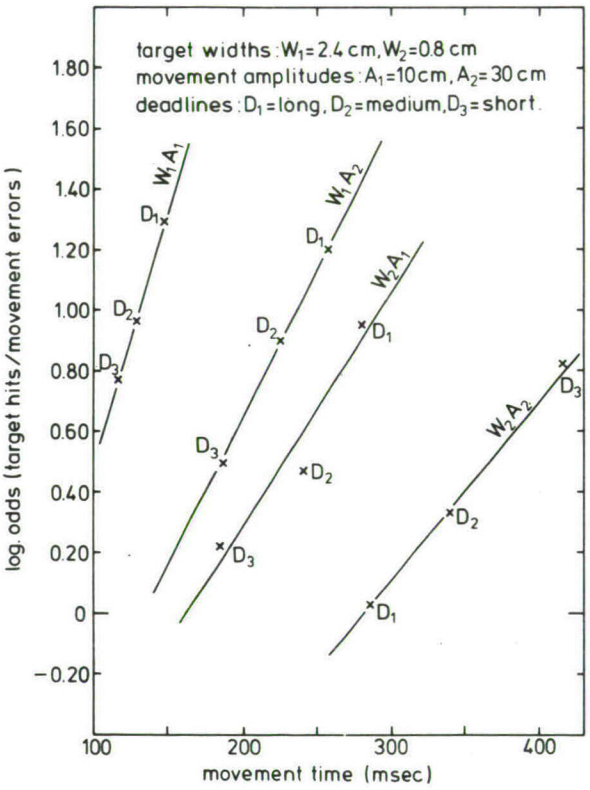

Fig. 2. Speed-accuracy trade-off functions between movement time (MT) and movement accuracy (log odds).

Discussion

Although the present results seem relatively clearcut, they require of course further confirmation with different types of tasks and preferably with more than three points on the speed-accuracy trade-off curve. Subject to such further confirmation, it seems that the relationship between the log odds which should perhaps now be referred to as Pew's law, applies to the speed and accuracy of MT as well as to the speed and accuracy of RT. Apart from its practical utility for the correction of unwanted shifts in the speed-accuracy trade-off criterion, its theoretical implication is that it suggests a similarity between the process of selecting a motor response prior to its execution and the structuring of a motor response during its execution.

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PAPER 4

AN ADDITIVE FACTOR EXPERIMENT WITH DRUGS, TIME UNCERTAINTY AND IMMEDIATE AROUSAL *

Summary

In reaction tasks a distinction can be made between structural independent variables which affect a change in the component processes which are necessary to proceed from stimulus to response completion, and functional independent variables which affect performance by bringing about a change in the state of the organism, which in turn may affect the efficiency of one or more of the component processes between stimulus and response. This study focuses on the relationship between four functional variables on performance in a visual choice task with reaction time (RT) and movement time (MT) as the main independent variables. The four functional variables were drug treatment (amphetamine, barbiturate, placebo), time-on-task, time uncertainty (which may be assumed to affect the preparatory state of the subject) and an auditory accessory stimulus (which may be assumed to elicit a change of state referred to as immediate arousal).

The experimental design was wholly within-subjects with 12 male university students serving as the subjects. The results indicated that manipulations of the auditory accessory and time uncertainty affected RT but not MT, and that there was a significant interaction between the effects of these two variables on RT. Time-on-task, on the other hand, affected MT as well as RT. Barbiturate (versus placebo) increased RT but had no effect on MT, and the barbiturate effect on RT was unaffected by time-on-task or by variations in time uncertainty and the auditory accessory. Amphetamine (versus placebo) decreased MT but had no effect on RT, although a second-order interaction between the effects of amphetamine, time uncertainty and time-on-task indicated that amphetamine tended to decrease RT as time uncertainty and time-on-task were increased. The results were interpreted within the framework of Sternberg's additive factor analysis of processing stages. This allowed some specific inferences and hypotheses about the selective influence of the independent variables on specific processing stages.

* To be submitted to Acta Psychologica

Introduction

Functional and structural variables

The level of performance in an information processing or motor task can be influenced by a great many independent variables, which can be broadly categorized as either 'structural' or 'functional' (e.g. Sanders, 1977). That is to say, an independent variable can be categorized as structural if it involves a change in the information that needs to be processed or the responses that have to be carried out, and as functional if it brings about a change in performance without changing the information processing and response requirements of the task. More specifically, within the framework of reaction time experiments structural variables can be defined as task variables which involve a change in either the stimulus to be responded to, the response to be carried out or the relationship between stimulus and response. Examples are changes in the detectability or complexity of the stimulus, changes in the complexity of the required motor response and changes in the compatibility between stimulus and response. Functional variables, on the other hand, affect performance by bringing about a change in the state of the organism, which in turn may affect the efficiency of one or more of the component processes between stimulus and response. Some of the variables that can be regarded as functional variables, are the so-called "stresses" like drugs, sleep-deprivation and time-on-task. These have usually relatively long-duration effects and can therefore be denoted as "tonic" functional variables. Other variables like knowledge-of-results and time uncertainty (i.e. uncertainty about the time at which the reaction stimulus will be presented) have shorter effects but can also be regarded as functional because they have a clear effect on performance while the operations that need to be carried out remain the same. The short-duration functional variables can be denoted as 'phasic' to distinguish them from tonic-functional variables.

Most reaction time research carried out during the last decade has focused on manipulating the effects of structural variables, and an important research line was prompted by Sternberg's (1969) additive factor method, which makes it possible to identify 'stages' in the reaction process. According to the logic of this method, it can be inferred that two or more task variables affect independent processing stages if they show additive contributions to reaction time (RT), while an interaction between the effects of different task variables can be assumed to indicate that these variables

affect the same processing stage. For instance, it has been consistently shown that the effects of visual stimulus degradation and S-R compatibility are additive (Sternberg, 1969; Shwartz et al., 1977; Sanders, 1980a), which leads to the conclusion that these two variables affect different processing stages which may be referred to as stimulus encoding and response selection. (The assumption being that visual stimulus degradation affects stimulus encoding and S-R compatibility affects response selection.) Systematic application of this method allows new findings to be integrated into a common theoretical framework which could eventually lead to a complete picture of the processing stages which make up reaction time. (For a good current review, see Sanders, 1980b).

Drugs and other stresses

Such a common theoretical framework is less clear when one looks at the effects of functional variables, but (as will be argued from here on), the additive factor method can also be fruitfully applied in this case.

Considering first the effects of stresses such as drugs and time-on-task, it has been well-established that these can affect reaction time (e.g. Wilkinson, 1969; Broadbent, 1971; Sanders and Bunt, 1971). In the past these effects have commonly been attributed to variations in the organism's general level of arousal (e.g. Easterbrook, 1959; Berlyne, 1960). More recently, however, it has become evident that arousal as a unidimensional concept cannot account for all the evidence. Firstly, it has been shown that the intercorrelation between different physiological indices of arousal is quite low (Lacey, 1967). Secondly, the research on the joint effects of different stresses has generated a set of results which cannot be accounted for in terms of a single arousal system (Broadbent, 1971). For these and other reasons, there are now several theories which each propose two or more arousal systems (e.g. Broadbent, 1971; Pribram and McGuiness, 1975). Without going into the specifics of each of these theories, the general implication is that different stresses may affect different processes, and that the effect of a particular stress on performance will be dependent on the type of task involved; i.e. a stress will only affect performance if it affects processes involved in carrying out that task.

If one takes this general hypothesis as a point of departure for further investigations about the effects of stresses on reaction time, it follows that to account for an effect of a stress in a reaction task one has to find out which of the processes involved in carrying out that task are

affected by that stress. Here, the logic of the additive factor method can be applied to the relationship between the effects of stresses and the effects of structural task variables. If a stress and a task variable show an interaction in their effect on the RT, it can be inferred that that particular stress affects the processing stage associated with the task variable. For instance, if the task variable is stimulus degradation, it can be inferred that that stress affects the stimulus encoding stage. Specific examples of this line of research can be found in the field of drug research, such as the investigations of the effects of marihuana by Darley et al. (1973) and alcohol by Tharp et al. (1974). The latter study indicated that alcohol consistently impaired response selection but had no effect on stimulus encoding. Another aspect of these results was that the relationship between the structural task variables remained unaffected by drugs. This was also found in later additive factor experiments by for instance Frowein (1981) with amphetamines and barbiturates and by Sanders et al. (1981) with sleep deprivation. Thus, it appears that tonic-functional variables such as drugs and sleep deprivation may have selective effects on individual stages in the reaction process, but that the organization of stages remains unaffected by the drugs. This is important to note because it bears witness to the robustness of the stage structure.

Time uncertainty

With regard to the effects of phasic-functional variables, the additive factor method can be applied in the same manner. This is illustrated for instance, by research carried out on the effect of time uncertainty. Time uncertainty can be varied in different ways. If the reaction stimulus is preceded by a warning stimulus, time uncertainty can be increased by increasing the foreperiod between the warning stimulus and the reaction stimulus. If there is no warning stimulus, time uncertainty can be increased either by making the inter-stimulus interval longer or by making it more irregular. In any of these cases, an increase in time-uncertainty will bring about an increase in RT (e.g. Karlin, 1959; Sanders, 1965; Lisper and Törnos, 1974). To account for this it has usually been postulated that an increase in time uncertainty will impair the subject's preparation to respond (e.g. Bertelson, 1967; Näätänen and Merisalo, 1977). Within the context of a stage analysis this implies that such a change in the preparatory state will influence the duration of one or more of the processing stages, and that such a stage or stages may be located by investigating

the relationship of the effects of time uncertainty with the effects of other task variables on RT. In this respect, the effect of time uncertainty has been shown to be additive with the effects of visual stimulus intensity (Raab et al., 1961; Sanders, 1977), visual stimulus degradation (Frowein and Sanders, 1978a) and S-R compatibility (Sanders, 1977). This suggests that the stages involved in stimulus processing and response selection are unaffected by time uncertainty, and that time uncertainty must affect RT via some other stage in the reaction process. The likely candidate is then a stage which occurs further on the output side. Thus Sanders (1970, 1977) postulated that time uncertainty might affect a 'motor adjustment' stage which would occur after response selection and prior to response execution. This was further supported by Sanders (1980a) who instructed subjects to tense the muscles necessary to initiate the response prior to the reaction stimulus. This instruction brought about a shortening of RT, and this effect was greater in the case of low time uncertainty. Thus, it may be concluded that time uncertainty affects the same stage as preparatory muscle tension, and it is thus quite plausible to denote this stage as 'motor adjustment'.

Immediate arousal

On the other hand, Sanders and Wertheim (1973) and Sanders (1975) also found an interaction between auditory stimulus intensity and time-uncertainty. On first consideration this seems contradictory to the motor preparation hypothesis of time-uncertainty, because auditory intensity is clearly an input variable. However, it was postulated by Sanders and Wertheim (1973) and Sanders (1975) that loud auditory tones have the ability to bring about a very fast change in the state of the organism which may be called "immediate arousal", a term coined previously by Bertelson and Tisseyre (1969). This in turn could enhance the efficiency of the motor adjustment stage, so that the time spent during this stage would be jointly affected by immediate arousal and the preparatory processes occurring prior to stimulus onset. In support of this hypothesis, it has also been found that the effect of time uncertainty is greater with soft auditory reaction stimuli than with loud auditory stimuli (Sanders, 1977, 1980b; Sanders and Andriessen, 1978; Niemi, 1979); although it was also found that the interaction between auditory intensity and time uncertainty did not occur in incompatible choice tasks, which led to the additional hypothesis that the effect of immediate arousal may be suppressed in these in-

compatible tasks (Sanders, 1977; Sanders and Andriessen, 1978).

Summing up the discussion up to this point; the additive factor method can be usefully employed to identify different processing stages by looking at the relationship between different structural task variables. Secondly, an investigation of the relationship between the effects of structural task variables on RT and the effects of functional variables (tonic as well as phasic) can be useful when investigating the effects of these functional variables on individual processing stages. Thirdly, as is evident from Sanders' experiments on 'immediate arousal' and time uncertainty, the additive factor method can also be applied to investigate the relationship between different functional variables. In this case, the logic of the additive factor method again dictates that different variables affect different processing stages if they have additive effects on RT, and that they affect a common processing stage, if their effects show an interaction.

Aim of experiment

The present experiment is an example of this third application of the additive factor method. It investigates the joint effects of different phasic-functional and tonic-functional variables with particular emphasis on the effects of barbiturate and amphetamine. In a prior experiment, Trumbo and Gaillard (1975) investigated the effects of a barbiturate and an amphetamine in a simple reaction task with sensory modality (visual versus auditory), time uncertainty and time-on-task as the other variables. They found that amphetamine shortened RT when the reaction stimulus was visual but not when it was a loud tone. Moreover, this effect only occurred under conditions of high time uncertainty and it increased as a function of time-on-task. Contrary to this, the size of the barbiturate effect was not influenced by time uncertainty and time-on-task, and it occurred in the auditory rather than the visual condition. To account for these selective effects, Trumbo and Gaillard referred to Sanders and Wertheim (1973) and postulated that amphetamine served to maintain an adequate level of preparation when this was not already enhanced by the immediate arousal elicited by the loud tone. Barbiturate, on the other hand, was postulated to suppress the immediately arousing effect of the auditory stimulus.

In a general sense, Trumbo and Gaillard's explanation fits in with the hypothesis that depressants such as barbiturates have their greatest effect when the task situation is somehow arousing, while stimulants such

as amphetamines have a greater effect when the task situation is not arousing (e.g. Frankenhauser and Post, 1966). This more general hypothesis is also consistent with some results obtained by Frowein and Sanders (1978b) which suggested that barbiturate has a greater effect on RT when the task involves time stress, and that amphetamine is more likely to affect performance when there is no time stress. On the other hand, an arousal explanation of this type does not specify which of the component processes involved in carrying a reaction task are affected. A stage analysis of the data may provide more information regarding this point.

Interpreting Trumbo and Gaillard's data in terms of such a stage analysis, these data suggest that both amphetamine and barbiturate affect the motor adjustment stage. With respect to the amphetamine effect, this may be inferred, firstly from its interaction with time uncertainty and, secondly from its dependence on stimulus modality (which suggests that with auditory stimuli, the effect of amphetamine on motor adjustment is counteracted by the effect of immediate arousal). With respect to barbiturate, an effect on motor adjustment is suggested, firstly by its interaction with stimulus modality (which suggests that, with auditory stimuli, barbiturate depresses the immediate arousal effect on motor adjustment), and secondly by a tendency, in the auditory condition, for the barbiturate effect to interact with time uncertainty.

It should be remembered, however, that Trumbo and Gaillard's experiment was not set up as an additive factor experiment. Firstly, they used a simple RT task, whereas choice RT tasks are more appropriate for this method (Sternberg, 1969). Secondly, they used sensory modality as an independent variable, which is really not a suitable variable for additive factor analysis (e.g. Sanders, 1980b). Also their explanation of drug effects in terms of immediate arousal was essentially a post hoc explanation which may be questioned because the operationalization of immediate arousal in terms of the sensory modality of the reaction stimulus (loud-auditory versus visual) means that the immediately arousing function of the stimulus was confounded with its cueing function. Finally, there was some reason to doubt their results because they did not find a barbiturate effect on visual RT whereas subsequent studies in our laboratory have shown quite clear barbiturate effects in visual RT tasks (e.g. Frowein and Sanders, 1978b; Frowein, 1981).

The main purpose of the present experiment was to investigate once more the relationship between on the one hand the effects of barbiturate

and amphetamine and on the other hand the effects of time uncertainty and immediate arousal, and to avoid confounding immediate arousal with the cueing function of the stimulus. To achieve the latter, an auditory accessory stimulus was presented simultaneously with the reaction stimulus in a visual choice task. The literature shows that the presence of such an auditory accessory will speed up reaction time (e.g. Bernstein et al., 1973; Nickerson, 1973), and this effect has been attributed to the 'automatic alerting' effect of auditory stimuli (Posner et al., 1976) which can be regarded as another term for 'immediate arousal'. In this experiment there were three accessory conditions (no accessory, a soft tone and a loud tone), and time uncertainty was manipulated by either including a visual warning signal 1.5 seconds prior to the reaction signal or not including such a warning signal.

Thus, assuming that the auditory accessory will elicit immediate arousal, it was predicted that the effect of increased time uncertainty would be counteracted by the accessory effect. Furthermore, on the basis of an additive factor interpretation of Trumbo and Gaillard's data the effect of each of the two drugs should interact with the effect of both time uncertainty and the accessory.

The visual choice task was the same as used by Frowein and Sanders (1978a) and Frowein (1981), i.e. the subject was required to make a finger movement to one of four targets, which allows the measurement of both reaction time (RT) and movement time (MT). With this task Frowein and Sanders (1978a) found that pattern degradation, S-R compatibility and time uncertainty had additive effects on RT and no effect on MT, which led them to conclude that pattern degradation, S-R compatibility and time uncertainty affect three consecutive processing stages, i.e. stimulus encoding, response selection and motor adjustment; and that the MT reflects the duration of the subsequent response execution process. Using the same task but only with low time uncertainty, Frowein (1981) found that barbiturate affected only the RT and that this effect interacted with the effect of pattern degradation, which was interpreted as an effect of barbiturate on stimulus encoding. Amphetamine affected only the MT and this effect was interpreted as a selective effect on response execution.

These conclusions differ from the predictions made on the basis of Trumbo and Gaillard's experiment, but it should be remembered that a drug may affect more than one processing stage. Thus it may well be that barbiturate affects motor adjustment as well as encoding, but it would of

course be inconsistent with the data obtained by Frowein (1981) if a barbiturate effect on MT rather than RT is found.

With respect to amphetamine, the data by Frowein (1981) did not show an effect on RT, which seems to preclude an effect on motor adjustment. However, because high as well as low time uncertainty was used in the present experiment, it was reasoned that high time uncertainty could provide the necessary precondition for an amphetamine effect on RT. That amphetamine may affect RT, given the right conditions, was already evident from other experiments in our laboratory (Trumbo and Gaillard, 1975; Frowein and Sanders, 1978b; Frowein, 1979).

Also, the task-duration was much longer in the present study than in the experiment by Frowein (1981). Apart from the fact that this may further enhance the amphetamine effect (e.g. Weiss and Laties, 1962), it also provides an opportunity to study the effect of time-on-task in its own right. In particular, it was reasoned that the data of this experiment may lead to specific conclusions about possible effects of time-on-task on motor adjustment and response execution.

Method

Subjects

The subjects were 12 healthy male students from the University of Utrecht with an age range from 20 to 30 years. They were paid Hfl. 60,- a day for participating in the experiment, and a bonus of approx. Hfl. 5,- to Hfl. 10,- was awarded on the basis of their performance during the experimental task.

Drug treatment

The drug conditions consisted of an amphetamine derivative (20 mg phentermine HCl), a barbiturate (100 mg pentobarbital Na) and a placebo. The drug treatment was always administered by the subject himself by means of a suppository.

Experimental task and apparatus

The task was a visual four-choice reaction task with reaction time and movement time as response measures. The subject was seated in a sound attenuating cubicle at a sloping desk. The visual signals consisted of

flashes generated by a Nixie tube situated about one meter in front of the subject. The imperative signal consisted of a 200 msec flash of a diagonal and a horizontal line joining in one of the four corners of the Nixie Tube. The interval between imperative signals was always 12 sec. This stimulus situation is represented in Fig. 1. The index finger of the subject's preferred hand was resting on the release button, and his task was to make a forward movement with the index finger to press one of the four target buttons. The correct target button was indicated by the joining point of the diagonal and horizontal line. Subjects were specifically instructed

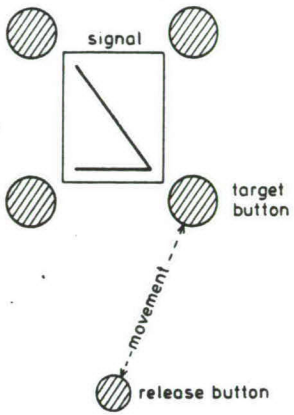

Fig. 1. Schematic representation of the stimulus situation.

to make the movement as rapidly as possible without hesitation about which button to touch. The four targets consisted of flat touch buttons with a diameter of 2.5 cm. The distance between the release button and the target button was 13 cm for the two bottom targets and 20 cm for the two top targets. The preprogrammed signal presentation and the registration of the responses was performed by the PSARP system (van Doorne and Sanders, 1968). The reaction time (RT) was defined as the interval between the onset of the imperative signal and the release of the release button, and the movement time was defined as the interval between the release of the release button and the touching of the target button.

Time uncertainty was varied by the presence or absence of a visual warning signal consisting of a 500 msec flash of the Nixie tube with all elements activated in the pattern of a Union Jack. The onset-onset interval between the warning signal and the imperative signal was always 1.5

seconds.

The auditory accessory stimulus consisted of a 200 msec tone which was presented simultaneously with the imperative signal. The tone was presented via a loudspeaker in front of the subject. The loudness of the auditory accessory was either 0 dB, 35 dB or 80 dB.

Design and procedure

A within-subjects design was used with drug treatment (barbiturate, amphetamine, placebo), loudness of the accessory tone (no tone, 35 dB, 80 dB), time uncertainty (with or without warning signal) and time-on-task as independent variables. The different drug treatments were administered at the same time of day at weekly intervals, and the order of treatment was varied between subjects in the manner of a Latin square. On each day of testing a subject received all of the six task conditions during a 2½ hour uninterrupted session consisting of 750 trials. Time-on-task effects were assessed by partioning the data obtained during the 2½ hour session into five ½-hour periods of 150 trials. The other six task conditions were randomly distributed over trials with the limitation that each condition occurred 25 times within a block of 150 trials. Hence, the total number of trials used in the data analysis was 12 (subjects) x 3 (drugs) x 3 (accessory loudness) x 2 (time uncertainty) x 5 (periods) x 25 (trials per period) = 27.000 trials.

For each S the program consisted of one training day and three experimental days at weekly intervals. In addition, each subject received a medical examination involving blood and urine tests on the morning of the training day. On each experimental day, two subjects were tested one after the other. Half the subjects always received the suppository at 9.00 a.m. and carried out the experimental task between 10.30 and 13.00, while the other half of the subjects received the suppository at 11.30 and carried out the task between 13.00 and 15.30. Thus there was always a 1½ hour rest period between the administration of the suppository and the experimental session. This procedure was followed to ensure a stable plasma concentration during the experimental sessions (Breimer, 1974; Vree, 1978). Allocation of drug conditions was 'double-blind' in the sense that neither the experimenter nor the subjects knew on which days the different drug conditions would be administered, but they were informed about the nature of the drug treatments used in this experiment.

Results

The principle measures of performance were the means of RT's and MT's, which were computed for each individual session and analyzed by separate analyses of variance. In addition, planned comparisons were carried out to test the effects of barbiturate and amphetamine against placebo, and to allow a separate assessment of the effect of the intensity of the accessory (35 dB vs. 80 dB) and the effect of the mere presence of the accessory (0 dB vs. 35 dB). Interactions among these effects and between these effects and the effects of the other variables (time uncertainty, and time-on-task) were also tested in accordance with the planned comparisons procedure. The percentages of errors were also computed for each individual session and analyzed in the same manner, but this did not show up any significant main effect of interactions. Suffice to say that the average percentage of errors remained below 2% for all conditions.

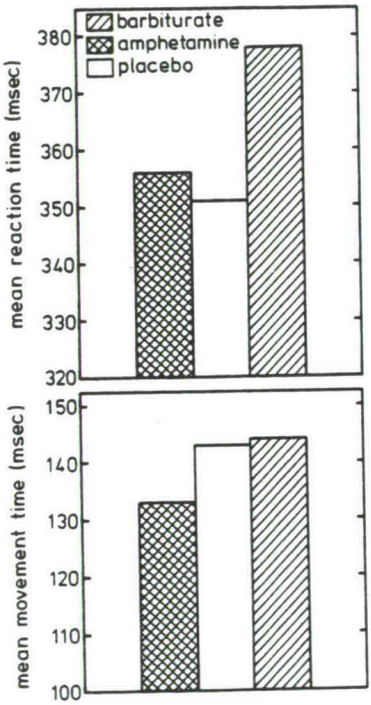

Fig. 2. Main effects of drug treatment on RT and MT.

Main drug effects on RT and MT

The histograms in Fig. 2 picture the main effects of barbiturate and amphetamine on both the mean RT and the mean MT. Babiturate slowed down the RT ($F = 11.42$; $df = 1,18$; $p < .01$) but had no effect on the MT ($F < 1$); and amphetamine had no effect on the RT ($F < 1$) but speeded up the MT by about 10 msec. Although this last difference was only marginally significant ($F = 3.16$; $df = 1,18$; $p < .10$), the pattern of results replicates the previous finding by Frowein (1981) were amphetamine did have a significant effect on the MT but not on the RT. It seems therefore justified to conclude that there was a real shortening effect of amphetamine on the MT.

Reaction times

The effects on mean RT of drug treatment, time uncertainty and auditory accessory are pictured in Fig. 3. There were large main effects of both time uncertainty ($F = 213.33$; $df = 1,9$; $p < .01$) and accessory ($F =$

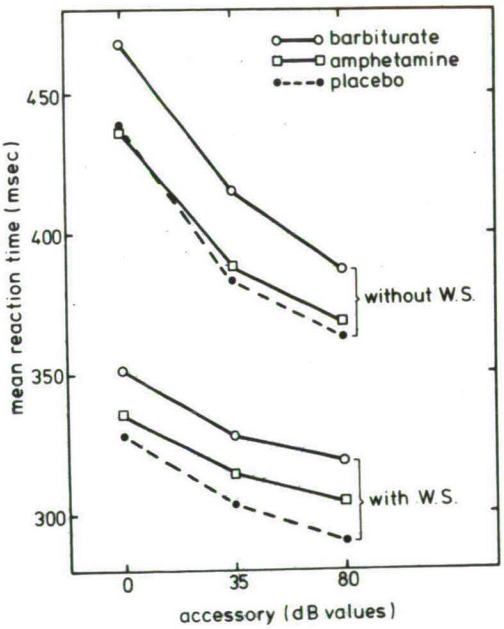

Fig. 3. Effects of time uncertainty, drug treatment and accessory on RT.

132.18; df = 2,18; $p < .01$) and there was also an interaction between these two ($F = 69.40$; df = 2,18; $p < .01$). Furthermore, the additional planned comparisons analysis showed significant differences between the accessory conditions of 0 dB and 35 dB ($F = 114.08$; df = 1,18; $p < .01$) and between the 35 dB and 80 dB conditions ($F = 27.01$; df = 1,18; $p < .01$); and each of these two differences showed a significant interaction with the effect of time uncertainty ($p < .01$ in both cases). Thus the presentation of the auditory accessory served to diminish the effect of time uncertainty on RT, and this influence was greater when the loud than when the soft accessory was presented.

Regarding the relationship between these task variables and the barbiturate effect, the data indicate that the barbiturate effect was additive with the effects of both time uncertainty ($F < 1$) and accessory ($F < 1$), and the second-order interaction between the effects of accessory, time uncertainty and barbiturate-versus-placebo was also not significant ($F = 1.30$; df = 2,36; N.S.).

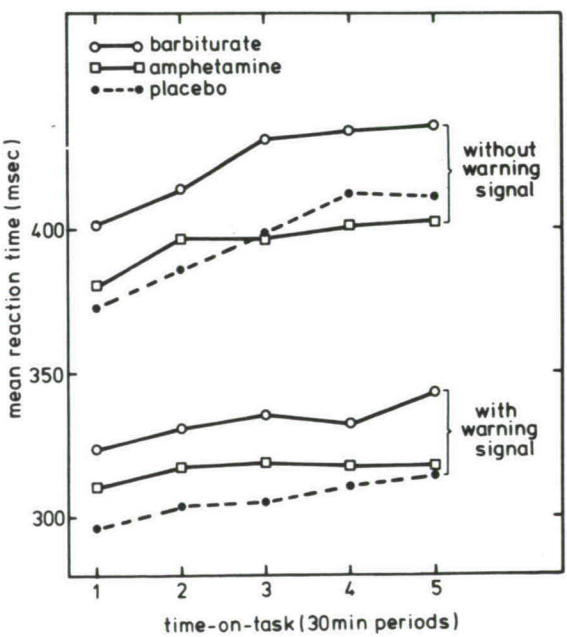

Fig. 4. Effects of drug treatment, time uncertainty and time-on-task on RT.

With regard to the amphetamine effect there were marginal interactions with the effects of both time uncertainty ($F = 3.42$; $df = 1,18$; $p < .10$) and accessory ($F = 3.04$; $df = 2,36$; $p < .10$), but the second-order interaction between time uncertainty, accessory and amphetamine-versus-placebo was clearly not significant ($F < 1$).

Fig. 4 pictures the joint effects of time-on-task, time uncertainty and drug treatment on mean RT. The main effect of time-on-task was significant ($F = 4.09$; $df = 4,36$; $p < .01$) and there was a significant interaction with the effect of time uncertainty ($F = 18.76$; $df = 4,36$; $p < .01$), but the relationship between the effects of time-on-task and accessory appeared to be additive ($F = 1.03$; $df = 8,72$; N.S.). The effect of time-on-task on RT was also additive with the effects of barbiturate ($F < 1$), and none of the higher order interactions involving the effects of time-on-task as well barbiturate approached significance. Regarding the effect of amphetamine-versus-placebo, there was a marginal interaction with time-on-task ($F = 2.04$; $df = 4,72$; $p < .10$), but none of the higher order interactions involving the effects of amphetamine and time-on-task approached significance.

Movement times

There were no significant effects on the mean MT of either time uncertainty, accessory or the interaction between these two ($F < 1$ in all cases). The effects of drug treatment and time-on-task are pictured in Fig. 5. The mean MT increased significantly as a function of time-on-task ($F = 13.95$; $df = 4,36$; $p < .01$), and as mentioned before, there was also

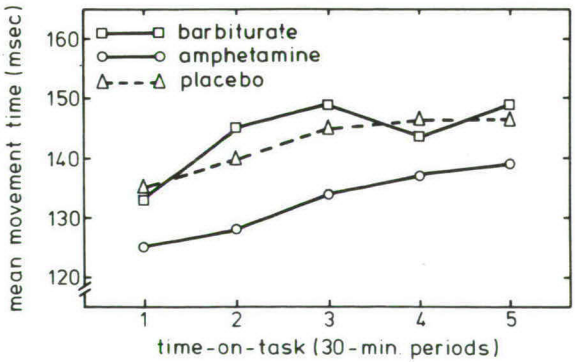

Fig. 5. Effects of drug treatment and time-on-task on MT.

a marginal effect of amphetamine ($F = 3.10$; $df = 1,18$; $p < .10$). However, there was no significant interaction between the effects of time-on-task and amphetamine ($F = 1.17$; $df = 4,72$; N.S.), and there were no other interactions which approached significance.

Discussion

Considering first the evidence with respect to the structural organization of stages, the interaction between the effects of the accessory and time uncertainty on RT is consistent with the hypothesis that these two variables affect a common processing stage. Thus, on the assumption that time uncertainty affects the motor adjustment stage, it would seem that the accessory would also affect this stage (presumably through the immediate arousal mechanism). However, it should be noted that the effect of time-on-task on RT showed an interaction with the effect of time uncertainty but additivity with the accessory effect. This suggests two stages, one affected by the accessory and time uncertainty, and another affected by time uncertainty and time-on-task. Taking into account also that time-on-task was the only task variable which affected both the RT and the MT, the model pictured in Fig. 6 could account for the effects of these three variables.

This model is not greatly different from the model proposed by Sanders (1980a) which also proposes two motor stages in RT, i.e. motor programming and motor adjustment. This is also be consistent with the work of other

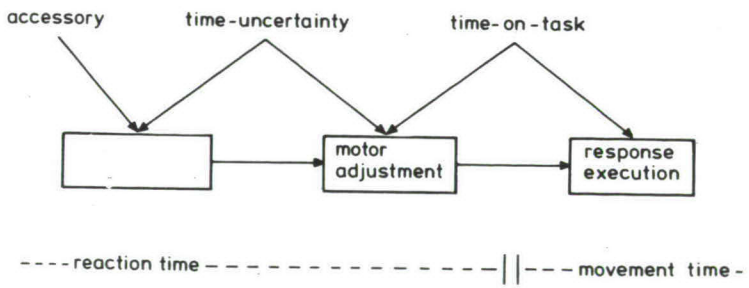

Fig. 6. An inferred model of stages based in the relationship between the effects of time uncertainty, time-on-task and accessory on RT and MT; one of the stages has not been named because its nature is still unclear.

recent theorists (e.g. Klapp, 1977; Kerr, 1978) who distinguish between abstract programming (with respect to such aspects as the direction and the extent of a movement) and instructions to specific muscles. Thus, it could be postulated that time uncertainty and accessory affect an abstract motor programming stage, whereas time uncertainty and time-on-task jointly affect the subsequent motor adjustment stage during instructions to specific muscle would be given. However, in Fig. 6 the nature of the stage affected by the accessory and time uncertainty is left open, because recent experiments by Sternberg et al. (1980) and Spijkers (in preparation) indicate that the effect of time uncertainty on RT is additive with the effects of variables (such as response duration and the length of verbal utterances) which are usually assumed to affect motor programming. It may well be that time uncertainty and the accessory do not affect motor programming, but an additional stage after motor programming and before motor adjustment. Sternberg et al. (1980) suggest such a stage which they denote as motor command.

Looking at the effects of the two drugs, the first conclusion is that the data accord well with the previous experiment by Frowein (1981) where the same task was used. Amphetamine speeded up the MT rather than the RT and barbiturate had the reverse effect; it slowed down RT but had no significant effect on MT. Second, there was no interaction between the barbiturate effect on RT and either the effect of the accessory or the effect of time uncertainty. Thus the data show no support for the hypothesis that barbiturate suppresses immediate arousal or has an effect on either of the two stages proposed in Fig. 6. Furthermore, taking into account also that there was no effect of barbiturate on the MT, these results clearly indicate that the effect of barbiturate will not be found at the output side of processing.

Third, the effect of amphetamine on RT again copied the results obtained by Frowein (1981), i.e. amphetamine had no main effect on RT. On the other hand, there were marginally significant interactions of amphetamine with the effects of time uncertainty and time-on-task on RT. This is consistent with the results of Trumbo and Gaillard (1975) and suggests that amphetamine affects the motor adjustment stage. Thus, taking into account also the amphetamine effect on MT, the results clearly indicate that amphetamine (contrary to barbiturate) affect the output side of the reaction process.

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PAPER 5

EFFECTS OF TWO COUNTERACTING STRESSES ON THE REACTION PROCESS*

Summary

The effects of an amphetamine and sleep deprivation were investigated in a visual two-choice RT task with reaction time (RT) and movement time (MT) as response measures. Independent task variables were time uncertainty and movement amplitude. The RT-data showed that sleep deprivation lengthened RT and that this effect was nearly totally suppressed when amphetamine was administered. Also, the effects of both amphetamine and sleep deprivation were greater with high than with low time uncertainty. This was interpreted in terms of Sternberg's additive stage analysis, i.e. on the assumption that time uncertainty affects a motor adjustment stage preceding motor execution,it was inferred that this stage is affected by sleep deprivation as well as amphetamine. Furthermore, an analysis of morning versus afternoon sessions indicated that these effects were more prominent in the afternoon than in the morning. The movement data showed that both the speed and the accuracy of the movements was improved by amphetamine and impaired by sleep deprivation. However, there was no clear interaction between these two stresses and the possibility was suggested that they may affect different mechanisms during movement execution.

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Introduction

This paper describes an experiment about the effects on task performance of two counteracting stresses: sleep deprivation and amphetamine. Its aim is to relate these effects to some of the component processes involved in carrying out a task; in this case a choice reaction task. We have tried to achieve this by investigating the relationship between the effects of these stresses and the effects of certain task variables.

The theoretical basis for this approach is provided by the additive factor analysis of stages in reaction time (Sternberg, 1969). In accordance with this approach, it may be assumed that reaction time consists of a series of independent processing stages, and it may be inferred that different task variables affect separate processing stages if their respective effects on RT are additive, while an interaction between different task variables would mean that they affect at least one common processing stage. Following Sternberg, a number of investigators have applied this method to arrive at a more complete picture of the reaction process. Comprehensive reviews of this research were presented by Sanders (1977, 1980a). For the present, the following findings are relevant to formulate a working model of the reaction process.

Firstly, it has been consistently shown that visual stimulus degradation and S-R compatibility have additive effects on RT (Sternberg, 1969; Shwartz et al. 1977; Frowein and Sanders, 1978; Sanders, 1980a). This indicates that they must affect different processing stages which may be referred to as stimulus encoding and response selection. Secondly, it has been shown that time uncertainty is additive with each of these two variables. Time uncertainty can be varied in different ways. If the reaction stimulus is preceded by a warning signal, time uncertainty can be increased by increasing the foreperiod between the warning signal and the reaction stimulus. If there is no warning signal, time uncertainty can be increased either by making the inter-stimulus interval longer or making it more irregular. In either of these cases, an increase in time uncertainty will bring about an increase in RT; and this effect appears to be additive with both visual stimulus degradation (Frowein and Sanders, 1978; Wertheim, 1980) and S-R compatibility (Posner et al., 1973; Sanders, 1977; Frowein and Sanders, 1978). This indicates that the stages involved in stimulus encoding and response selection are unaffected by time uncertainty, and that time

uncertainty must affect RT via some other stage in the reaction process. In this respect, Sanders (1977, 1980b) has postulated that time uncertainty affects a "motor adjustment" stage which would occur after response selection; i.e. if the subject knows when to expect the stimulus he would be better prepared to respond, and the motor adjustment stage would proceed more quickly. This is also consistent with an experiment by Sanders (1980a) who instructed subjects to tense the muscles necessary to initiate the response. This instruction brought about a shortening of RT, and this effect was greater in the case of low time uncertainty. Furthermore, there is also some physiological evidence that time uncertainty affects the motor adjustment stage. Gaillard (1978) has shown that the amplitude of the so-called contingent negative variation (CNV) in the EEG, which is mainly found in the derivation from the motor cortex, varies as a function of time uncertainty but is unaffected by stimulus degradation.

A third relevant finding for our working model is that stimulus degradation, S-R compatibility and time uncertainty which were found to have additive effects on RT, had no effect on the movement time (MT) when MT followed RT in a target-aiming response (Frowein and Sanders, 1978). This indicates that MT represents a separate process following on from stimulus encoding, response selection and motor adjustment. However, this motor execution process should not be conceived of as necessarily consisting of only one stage. For short ballistic movements below 200 msec, motor execution may be conceived as consisting of one stage because there is not enough time for visual feedback to play a role and it has been shown that other modes of feedback are not sufficient for adequate feedback control (Klapp, 1975). When movements become longer than 200 msec it may be assumed that feedback starts playing a role which probably increases with the complexity of the movement. Thus, with the reservation that more mechanisms may be involved, we may represent motor execution as one process in our working model pictured in Fig. 1.

This working model may serve as a framework to locate effects of stresses. If a stress and a task variable show an interaction in their respective effects on RT, it can be inferred that they affect a common processing stage, while additivity implies that they affect separate processing stages. Similarly, an effect of a stress on response execution can be inferred from its effect on MT.

In previous experiments in our laboratory we have investigated the

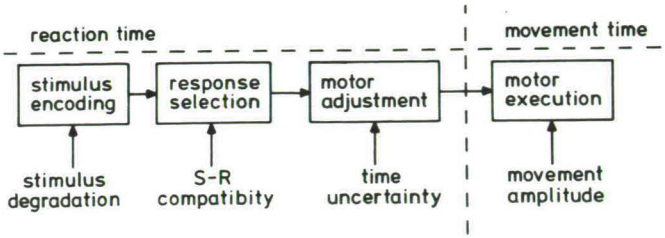

Fig. 1. Model of the reaction process.

separate effects of amphetamine and barbiturate in this manner. For the purposes of introducing the present experiment, it useful to review some of the amphetamine findings. Here the following points are relevant:

1. There is no evidence that amphetamine affects the stimulus encoding stage; Frowein (1981) found that the effect of amphetamine on RT was unaffected by visual stimulus degradation. Also, Frowein and Sanders (note 3) found no relationship between the effect of amphetamine and the effect of visual intensity.

2. The evidence regarding the effect of amphetamine on the response selection stage is more equivocal. Frowein (1981) found that there was a small but significant interaction of amphetamine with the effect of S-R compatibility on RT. It appeared in this case that amphetamine had an inhibitory effect on response selection: in the incompatible condition, amphetamine brought about longer RT's. However, a subsequent attempt to replicate this interaction proved unsuccessful (Frowein, note 1). In this experiment it was also found that the amphetamine effect on RT was additive with the effect of relative signal frequency. Because this variable has also been found to affect the response selection stage (e.g. Sanders, 1977), it appears that the weight of the evidence tilts towards concluding that amphetamine has no effect on the response selection stage.

3. Regarding the motor adjustment stage, the evidence is more consistent. Trumbo and Gaillard (1975) found that the effect of amphetamine on RT increased with time uncertainty and this interaction has recently been

replicated by Frowein (note 2). Thus, assuming that time uncertainty affects motor preparation, there is consistent evidence of an amphetamine effect on that stage.

4. Finally, there is also consistent evidence that amphetamine affects motor execution. In two recent experiments (Frowein, 1981; Frowein, note 1), with two different types of tasks and movement times ranging from about 120 msec to about 500 msec, it has been shown that amphetamine shortens the MT. Furthermore, in the second of these two studies, in which a task adapted from Fitts and Peterson (1964) was used with movement amplitude and target width as independent variables, the data showed that the amphetamine effect increased slightly as a function of movement amplitude but did not vary as a function of target width. Because the role of visual feedback was assumed to be greater with smaller targets, it was inferred that the amphetamine effect on MT could not be attributed to an amphetamine effect on visual feedback (i.e. encoding).

Thus, in summary, it appears that amphetamine selectively affects motor adjustment and motor execution. The present experiment investigates the effects on motor adjustment and motor execution of sleep deprivation as well as amphetamine. The task was again a two-choice task derived from Fitts and Peterson (1964) with reaction time and movement time as the main response measures. Time uncertainty and movement amplitude were the independent task variables.

Sleep deprivation was introduced as an extra stress because it has been shown in a variety of tasks that its effect on performance can be counteracted by amphetamine and that the size of the effect of amphetamine increases considerably in the presence of sleep deprivation (e.g. Weiss and Laties, 1962). Thus, if amphetamine and sleep deprivation have a similar relation in their effects on RT it could be inferred that they affect at least one common processing mechanism. In terms of our working model this would mean either that these two stresses affect the motor adjustment stage or that they affect a common mechanism during motor execution or that both of these possibilities are true.

That it is not implausible to suggest that sleep deprivation affects both motor adjustment and motor execution was suggested by some prior evidence from the literature. Firstly, it has been repeatedly shown that sleep deprivation affects RT (e.g. Lisper and Kjellberg, 1972; Glenville and Wilkinson, 1979). Secondly, the finding by Naitoh et al. (1973) that

the CNV-wave disappears as a function of sleep deprivation suggests that the latter has an effect on motor adjustment, because the aforementioned experiments by Gaillard (1978) indicate that the motor adjustment stage proceeds more slowly when the CNV is low or absent. Thirdly, an effect of sleep deprivation on motor execution was suggested by an experiment by Buck (1975) who investigated the effect of sleep deprivation in a step-tracking task and found prominent effects on MT as well as RT.

In addition, the experiment also allowed an analysis of time-of-day effects. This variable was included in the analysis because the experimental tasks were carried out twice: first in the morning and subsequently in the afternoon.

Method

Subjects

The subjects were 32 healthy male students from the University of Utrecht. They were allotted to two groups of 16 subjects each: a sleep-deprived group (S.D.) and a control group. One week before participating in the experiment, all subjects received a medical examination and were informed about the nature of the drug treatment conditions and the experimental task. They were paid Hfl. 75,- for each day of experimentation and an additional Hfl. 75,- was paid for each night of sleep deprivation.

Drug treatment

The drug conditions consisted of an amphetamine derivative (40 mg Phentermine HCl) and a placebo. The drug treatment was always administered by the subject himself by means of a suppository at either 9.00 or 9.25 a.m. The experimental sessions were started 1 hour after treatment and finished about 6 hours later (see Table I). This ensures a relatively constant plasma concentration across experimental sessions (Vree, 1973). Allocation of the drug treatment was double-blind in the sense that neither the subjects nor the experimenter knew on which days the different treatments would be administered.

Sleep deprivation

Sleep deprivation consisted of one night without sleep. Subjects in

the sleep deprived group (S.D.) were instructed neither to sleep nor to drink alcohol on days prior to S.D. and to arrive at the laboratory at 11.00 p.m. During the night and during the rest periods of the following day, they were under constant supervision and kept busy playing various games (cards, monopoly, etc.). Subjects in the control group were instructed not to use alcohol and to get a normal night's sleep on days prior to experimental days, and they were also kept busy with various games during the rest periods on experimental days.

Experimental task and apparatus

The experimental task was adapted from Fitts and Peterson (1964). The subject was seated at a sloping desk with in his preferred hand a lightweight stylus which rested on a slightly hollowed circular starting plate of 1 cm diameter. A red warning light (WL) of 1 cm diameter was mounted 5 cm above the starting plate. White reaction lights (RL) were mounted 2 cm to the right of the WL and 2 cm to the left of the WL. The subject's task was to fixate the WL and to hit the appropriate one of two metal target plates as quickly as possible when one of the two RL's came on. The target plates were positioned to the right and to the left of the starting plate and they were 0.7 cm wide and 10 cm long. Undershoot and overshoot plates of 3.5 cm wide and 10 cm long were positioned adjacent to each of the two target plates. The instructions specified that movements should be made without hesitation, and that movements in the wrong direction should never be corrected during the movement. For each trial, the stimulus sequence was started with a 1000 msec WL which was followed by a 200 msec RL. The cycle duration (i.e. the onset-onset interval between consecutive RL's) was either 7, 8 or 9 sec with a mean duration of 8 sec. The preprogrammed signal presentation and the registration of responses was performed by a PDP 11-03 computer with an internal clock. The reaction time (RT) was defined as the interval between the onset of the RL and the release from the starting plate, and the movement time (MT) was defined as the interval between the release of the starting plate and the touching of either one of the two target plates or one of the undershoot or overshoot plates which were mounted adjacent to the target plates. The task variables were movement amplitude and time uncertainty. Movement amplitude was either 10 cm or 30 cm as measured by the distance between the midpoint of the starting plate and the midline of the target plate. Time

uncertainty also had two levels and was varied by means of varying the interval between the onsets of WL and RL. With low time uncertainty, the onset-onset interval between WL and RL was 1 sec which was also the duration of WL. With high time uncertainty, the onset-onset interval was either 4, 5 or 6 sec with a mean interval of 5 sec.

Design and procedure

The independent variables were sleep deprivation (S.D. versus control), drug treatment (amphetamine versus placebo), time uncertainty (low versus high), movement amplitude (10 cm versus 30 cm) and time-of-the-day (morning versus afternoon). Sleep deprivation was varied between two groups of 16 subjects while the other independent variables were varied within subjects. For each group the program consisted of three separate days with one week in between days. The first day served as training day, while the next two days served as experimental days. On nights preceding each of the experimental days, the S.D. group was sleep-deprived; and for both the S.D. and the control group, drug treatment was varied between the two experimental days.

On each day, two pairs of subjects were run alternately in four morning sessions and four afternoon sessions of 20 min each. There was always a 60 min rest period between treatment administration and the beginning of the first session, and a 30 min rest period between consecutive sessions. For half the subjects, treatment was administered at 9.00 and the sessions started at 10.00 and finished at 16.10, while for the other half treatment was administered at 9.25 and the sessions started at 10.25 and finished at 16.35. The rest period between the fourth morning session and the first afternoon session occurred from 12.50 to 13.20 for the first half of subjects, and from 13.15 to 13.45 for the second half of subjects.

The task variables were varied between morning sessions and again in the same order between the afternoon sessions. The order of presentation of the drug conditions and of the conditions of movement amplitude and time uncertainty were counterbalanced, with the sequence of high and low time uncertainty counterbalanced within each sequence of movement amplitudes, and the sequence of movement amplitudes counterbalanced within each sequence of drug treatment conditions.

Thus for each subject the task conditions were the same for both the training and the two experimental days, with the exception that during

the training sessions, subjects received feedback about their performance, that is about the total times (RT + MT) and about the accuracy of their performance. They were also told that during the experimental day a bonus would be computed on the basis of their mean total time for correct responses, but that no bonus would be paid for sessions with more than 10% errors (which included incorrect decisions, undershoots and overshoots). During the experimental days no feedback was given.

The experimental task was always carried out in a sound-attenuating cubicle with dim ceiling illumination. Subjects could be observed by the experimenter via a T.V. monitor.

Results

The dependent variables were mean RT's and MT's, and the percentages of incorrect decisions (left/right errors), missed responses and movement errors (undershoot and overshoot). These measures were computed for each individual session and analyzed in separate analyses of variance.

Reaction times

The effects of time uncertainty, time-of-the-day, drug treatment and sleep deprivation are shown in Fig. 2. There were significant main effects of time uncertainty ($F = 90.33$; $df = 1,28$; $p < .001$), time-of-the-day ($F = 59.31$; $df = 1,28$; $p < .001$) and drug treatment ($F = 18.88$; $df = 1,28$; $p < .01$). The main effect of sleep deprivation was not significant ($F = 1.54$; $df = 1,28$; N.S.) but a planned comparison analysis with only the placebo condition included showed that sleep deprivation brought about a significant increase in RT when this effect was not counteracted by amphetamine ($F = 14.86$; $df = 1,28$; $p < .01$). This was also supported by a significant interaction between the effects of sleep deprivation and amphetamine ($F = 4.89$; $df = 1,28$; $p < .05$). Furthermore, the effect of sleep deprivation and the suppression of this effect by amphetamine were greater in the afternoon than in the morning. In the analysis of variance this was evident from significant interactions of sleep deprivation x time-of-the-day ($F = 8.04$; $df = 1,28$; $p < .01$) and sleep deprivation x drug treatment x time-of-the-day ($F = 5.20$; $df = 1,28$; $p < .05$).

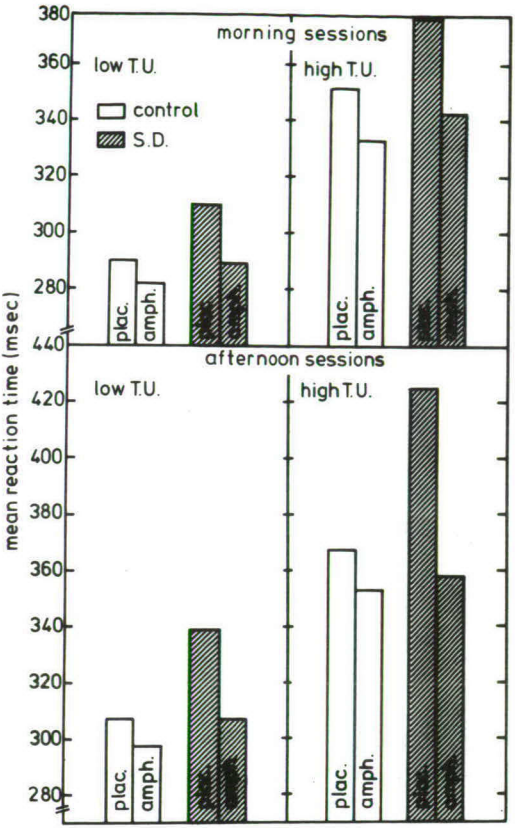

Fig. 2. Mean reaction time as a function of drug treatment, sleep deprivation, time uncertainty (T.U.)and time-of-the-day.

Regarding the relationship of the effect of time uncertainty with the effects of drug treatment and sleep deprivation and time-of-the-day there were significant interactions of time uncertainty x drug treatment ($F = 9.96$; $df = 1,28$; $p < .01$) and time uncertainty x time-of-the-day ($F = 6.58$; $df = 1,28$; $p < .01$). Although the analysis of variance did not show an interaction between time uncertainty and sleep deprivation ($F < 1$; $df = 1,28$; N.S.), a planned comparison analysis (with only the placebo condition included) indicated that the effect of sleep deprivation (when not suppressed by amphetamine) was greater with high time uncertainty ($F = 7.72$; $df = 1,28$;

$p < .01$). Furthermore, Fig. 2 also suggests that this interaction was greater in the morning than in the afternoon. In the analysis of variance this was indicated by a significant third-order interaction of sleep deprivation x drug treatment x time-of-the-day x time uncertainty ($F = 6.19$; $df = 1,28$; $p < .05$).

The effect of movement amplitude on RT is not pictured in Fig. 2. In fact, the mean RT's preceding longer movements were about 11 msec longer than those preceding short movements. This small effect was significant ($F = 11.14$; $df = 1,28$; $p < .01$) but showed no interaction with any of the other independent variables.

Movement times

The effects of movement amplitude, drug treatment, sleep deprivation and time-of-the-day are shown in Fig. 3. Movement amplitude had of course a highly significant main effect ($F = 1364.83$; $df = 1,28$; $p < .001$), but none of the interactions involving movement amplitude were significant.

Similarly there were also significant main effects of drug treatment ($F = 14.01$; $df = 1,28$; $p < .01$) and time-of-the-day ($F = 5.65$; $df = 1,28$; $p < .05$), but none of the interactions involving either or both of these variables were significant.

Sleep deprivation did not have a significant main effect on MT ($F < 1$; $df = 1,28$; N.S.), but a planned comparison analysis with only the placebo condition included was significant ($F = 5.97$; $df = 1,28$; $p < .05$). Thus, if the effect of sleep deprivation was not counteracted by the effect of amphetamine it appeared to lengthen MT.

Finally, as expected, there was no significant effect of time uncertainty on MT and none of the interactions involving time uncertainty was significant.

Movement errors

The percentages of movement errors (undershoots and overshoots) are pictured in Fig. 4. The analysis of variance showed marginally significant effects of sleep deprivation ($F = 3.99$; $df = 1,28$; $p < .10$) and drug treatment ($F = 3.29$; $df = 1,28$; $p < .10$), but the interaction between these two variables did not approach significance. Likewise there were no significant main effects or interactions involving movement amplitude or time-of-the-day.

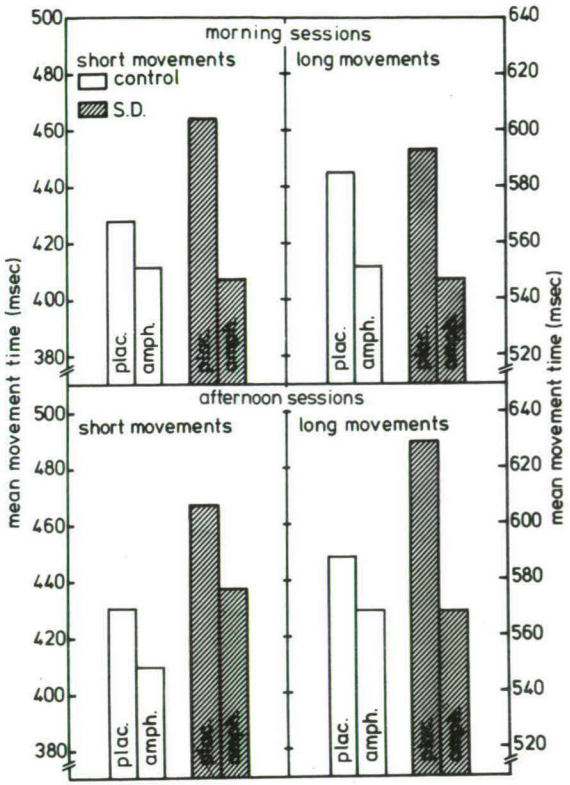

Fig. 3. Mean movement time as a function of drug treatment, sleep deprivation and movement amplitude (short = 10 cm; long = 30 cm) and time-of-the-day.

Incorrect decisions and missed responses

Incorrect decisions (left-right errors) and misses responses were computed separately. Incorrect decisions occurred very rarely (well below 1% for all conditions) and there was no evidence of an effect of any of the independent variables on these types of errors or of these variables affecting RT through changes in speed-accuracy trade-off.

The percentages of missed responses are shown in Table I. The analysis of variance showed significant main effects of sleep deprivation ($F = 6.30$; $df = 1,28$; $p < .05$) and drug treatment ($F = 10.66$; $df = 1,29$; $p < .01$),

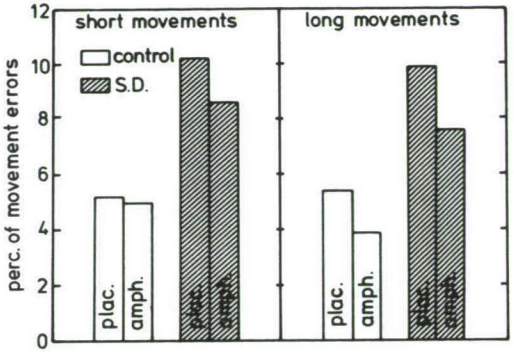

Fig. 4. Percentage of movement errors as a function of drug treatment, sleep deprivation and movement amplitude (short = 10 cm; long = 30 cm).

and there was also a significant interaction of sleep deprivation x drug treatment ($F = 16.62$; $df = 1,28$; $p < .01$). As shown in the table, amphetamine reduced the percentage of errors in the S.D. conditions but not in the control condition. Time-of-the-day also had a significant main effect ($F = 6.25$; $df = 1,28$; $p < .05$) and there was a significant interaction of time-of-the-day x sleep deprivation ($F = 5.97$; $df = 1,28$; $p < .05$), i.e. the effect of sleep deprivation was greater in the afternoon than in the morning. Other interactions involving time-of-the-day, sleep deprivation or drug treatment were not significant. Also there were no significant main effects or interactions involving either time uncertainty or movement amplitude.

Table I. Percentage of missed responses.

	TIME-OF-THE-DAY					
	Morning			Afternoon		
S.D. Control	S.D.	Control	diff	S.D.	Control	diff
Drug treatment						
Placebo	5.9	1.3	4.6	8.3	2.1	6.2
Amphetamine	2.5	2.3	0.2	5.9	1.8	4.1
diff	3.4	-1.0		2.4	0.3	

Discussion

The RT-data showed that the effect of sleep deprivation was greater in the afternoon than in the morning, and that in both the morning and the afternoon this effect was nearly totally suppressed when amphetamine was administered. Furthermore, there were first-order interactions of the effect of time uncertainty with the respective effects of sleep deprivation and drug treatment, and a third-order interaction between time uncertainty, sleep deprivation, time-of-the-day and drug treatment. Thus, on the assumption that time uncertainty affects the motor adjustment stage, the most parsimonious conclusion is that sleep deprivation and amphetamine affect motor adjustment in opposite directions, and that these effects are greater in the afternoon than in the morning.

However, it does not necessarily follow that motor adjustment is the only stage prior to motor execution which is affected by either amphetamine or sleep deprivation. With respect to amphetamine this conclusion is in fact not implausible because (as discussed in the Introduction) our previous research has shown little evidence of an amphetamine effect on either stimulus encoding or response selection. However, this is not true for sleep deprivation. A recent experiment by Sanders and Wijnen (note 4) showed a strong interaction of sleep deprivation with visual pattern degradation and an additive relationship between sleep deprivation and S-R compatibility. Interpreting these data together with the present results, it appears that sleep deprivation affects the stimulus encoding stage as well as the motor adjustment stage but that there is no effect of sleep deprivation on response selection. However, an inconsistency of this interpretation with the present data, is that amphetamine nearly totally suppressed the effect of sleep deprivation. If amphetamine counteracts the effect of sleep deprivation on motor adjustment but not on stimulus encoding, one would expect only a partial suppression. To account for this inconsistency it may be noted that the visual stimuli in the present experiment consisted of simple lights which would make little demand on the encoding stage. It would be expected that the suppression of the sleep deprivation effect by amphetamine would be less prominent if more complex stimulus patterns would be used.

With regard to the effects of sleep deprivation and amphetamine on motor execution, the present data showed that sleep deprivation brought

about longer MT's as well as more movement errors. Amphetamine, on the other hand, brought about shorter MT's and less movement errors. Thus, sleep deprivation and amphetamine had opposite effects on motor execution and this applied to the accuracy as well as the speed of movement. However, it is not clear whether these two stresses affect a common mechanism during motor execution. Although the figures suggest an interaction between sleep deprivation and amphetamine on MT as well as movement errors, this was not confirmed by the analyses of variance. A possible explanation of these results could go as follows. Because the movements in this experiment were always longer than 200 msec, it may be suggested that the first part is programmed before movement onset, while the second part is under feedback control. Thus, given this rather simple picture of motor execution, it may be postulated that sleep deprivation as well as amphetamine affect the preprogrammed part while sleep deprivation alone affects the efficiency of visual feedback. The latter would be consistent with the above-mentioned experiments which suggest that stimulus encoding is affected by sleep deprivation but not by amphetamine.

The effects of sleep deprivation and amphetamine on the missed responses appear to be of a different nature. It is clear that sleep deprivation increased the percentage of missed responses and that this effect was counteracted by the effect of amphetamine. However, it does not seem plausible to relate these effects to stages in the reaction process. For instance, the task variables in this experiment had no effect on the percentage of missed responses. Probably the simplest explanation is that the sleepy subjects started to catch little "micro-sleeps" (e.g. Dement, 1972). As it is well-known that amphetamine makes people less sleepy it is not surprising that amphetamine would counteract with this effect.

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PAPER 6

EFFECTS OF AMPHETAMINE AND BARBITURATE ON RT IN A MEMORY SEARCH TASK*

Summary

The effects of amphetamine and barbiturate on RT were investigated in a factorial experiment with 12 male students as subjects. The task, a visual binary choice task, was carried out under conditions of "varied" and "consistent" mapping which, according to Schneider and Shiffrin (1977), distinguishes between "automatic" and "controlled" processing respectively. Other independent task variables were memory set size and visual stimulus intensity. The results showed a significant lengthening effect of barbiturate (as compared to placebo) but no significant effect of amphetamine. Also it appeared that none of the task variables had a significant influence on the size of either of the two drug effects. Following Sternberg's additive factor method, these results suggest that the durations of neither the processing stage affected by visual stimulus intensity nor the memory comparison stage affected by memory set size, are influenced by either of the two drugs, and also that the distinction between automatic and controlled processing does not relate to the effects of these drugs. With reference to earlier findings, it was suggested that barbiturate selectively affects the encoding stage which occurs after the processing stage affected by stimulus intensity, and that amphetamine affects response-related processes.

* To be submitted to Psychopharmacology with A.F. Sanders as second author.

Introduction

Sternberg's additive factor method has been widely used in research which aims at studying the underlying processes which play a part in carrying out choice reaction tasks. The basic idea is that reaction time (RT) consists of a series of independent processing stages, and that these stages can be identified by looking at the relationship between the effects of two or more independent variables on RT. If different independent variables show additive contributions to RT, it is inferred that they are likely to affect independent processing stages, while an interaction is assumed to indicate that they affect the same processing stage (Sternberg, 1969). For instance, experiments with visual choice tasks have shown that the effect of S-R compatibility on RT is additive with the effect of visual stimulus degradation (Sternberg, 1969; Shwartz et al., 1977; Frowein and Sanders, 1978), and it can thus be inferred that these two task variables affect different processing stages which may be referred to as encoding and response selection. Similarly, the finding that S-R compatibility shows an interaction with the effect of relative S-R frequency on RT (e.g. Fitts et al., 1963; Broadbent and Gregory, 1965; Theios, 1975) suggests that the latter also affects the response selection stage. In this manner, the additive factor method has proved to be a powerful tool in exposing processing stages. Since its introduction it has generated a great number of experiments and up till now it has always been possible to fit the results into a plausible model of processing stages (e.g. Sanders, 1977, 1980).

In addition, the additive factor method can also be used to investigate the effects of drugs on these processing stages. In principle this means that one looks at the effect of a drug on RT in relation to the effects of certain task variables. If the effect of a drug on RT interacts with the effect of a task variable, it may be inferred that they affect at least one common processing stage. If, on the other hand, the drug and the task variable have additive main effects on RT, it should be inferred that they affect different processing stages. Examples of this type of research are the alcohol studies by Huntley (1972, 1974) and Tharp et al. (1974) which indicate that the effect of alcohol on RT interacted with the effects of task variables which are usually associated with response selection.

Selective effects of drugs on processing stages were also found by Frowein (1981). He investigated the effects of amphetamine and barbiturate in a visual choice reaction time with visual pattern degradation and S-R compatibility as independent task variables and reaction time and movement time as response measures. The data showed that barbiturate slowed down RT but had no effect on MT, and that amphetamine speeded up MT but had no effect on RT. Moreover, the MT was not affected by either pattern degradation or S-R compatibility. This is consistent with other studies such as Fitts and Peterson (1964), Kerr (1978) and Frowein and Sanders (1978) which suggests that the time necessary to execute a motor response is not affected by most independent variables which are known to have large effects on the preceding RT. Within the context of stage analysis this suggests that the processes involved in response execution are independent of the preceding stages of encoding and response selection. This means that the selective effects of amphetamine on MT and of barbiturate on RT, indicate that the former affects response execution whereas the latter affects one or more of the preceding stages. Regarding the effect of barbiturate on these preceding stages, it should be mentioned that its effect on RT showed a small but significant interaction with the effect of visual stimulus degradation, while it was additive with the effect of S-R compatibility. This suggests a selective effect on encoding while response selection remained unaffected.

The present experiment also looks at the relationship between the effects of these two drugs and the effects of task variables on RT. The task was a memory search task which means that the subject is presented with a stimulus such as a letter or a digit and has to decide whether or not this letter or digit belongs to a previously memorized set of letters or digits. Sternberg (1966, 1969) introduced this type of task and found that RT increases linearly as the size of the memory set was increased from one to four items, and that this effect was additive with the effects of visual stimulus degradation and relative S-R frequency. From this it was inferred that memory set size affects a separate processing stage which may be called "memory comparison" and which is separate from the stages affected by stimulus degradation and relative S-R frequency, i.e. encoding and response selection.

Our primary interest in the memory comparison stage was in finding out whether it is affected by barbiturate or amphetamine. In particular, the relationship between the effects of barbiturate and memory set size was

of interest. In a study with epileptic patients, McLeod et al. (1978) found that the effect of a barbiturate on RT increased as memory set size increased. Mohs, Tinklenberg, Roth and Kopell (Note 1), on the other hand, investigated the influence of both an amphetamine and a barbiturate in a memory search task and found that the effects of each of these drugs were additive with the effects of size of set.

A second interest in the memory search task derives from the work by Schneider and Shiffrin (1977) who used two versions of the memory search task, i.e. "varied mapping" and "consistent mapping". The varied mapping paradigm is not essentially different from Sternberg's original task in the sense that positive items (belonging to the memory set) were of the same category as negative items (not belonging to the memory set); for instance, both positive and negative items would consist of either digits or letters. In the consistent mapping paradigm, on the other hand, positive and negative items would not belong to the same category; for instance, positive items would be letters and negative items would be digits. Regarding their effect on RT, the main difference between these two paradigms was that the RT increased as a function of the size of the memory set in the varied mapping condition, but that there was no noticeable effect of memory set size on RT when consistent mapping was used. Schneider and Shiffrin related this difference to their two-process theory of information processing which distinguishes between "automatic" processing which occurs in parallel and makes little or no demands on attention, and "controlled" processing which is serial and requires attention. Varied mapping would require controlled processing, whereas automatic processing could be used during the consistent mapping condition. If this theory is correct, it could well be that either of the two drugs has a selective effect on automatic or controlled processing, and this should then be evident from a differential effect on RT as a function of varied vs. consistent mapping. In view of the usual link in the literature between effects of stimulant and depressant drugs, level of arousal and "attentional capacity" (e.g. Kahneman, 1973), it would follow that in particular controlled processing demands are selectively affected by the drugs. To investigate this possibility both types of mapping were used in this experiment.

An additional independent variable was visual stimulus intensity. As already mentioned, it had been previously shown that the effect of barbiturate interacts with the effect of visual stimulus degradation (Frowein, 1981). Thus, on the presumption that both stimulus intensity and degrada-

tion relate to visual processing (e.g. Stanovich and Pachella, 1977), it may be suggested that the barbiturate effect on RT will also show an interaction with the effect of stimulus intensity. On the other hand, it is indicated by a recent study by Sanders (1980) that the effect of stimulus intensity on RT is additive to the effect of stimulus degradation, suggesting that stimulus intensity affects a separate processing stage which precedes the encoding stage. Thus, if barbiturate has a rather general effect on visual processing, it may be expected that its effect on RT interacts with the effect of visual stimulus intensity. If, on the other hand, the barbiturate effect is more specific in the sense that only the encoding stage is affected it would be expected that the barbiturate effect is additive to the effect of stimulus intensity. In other words, the relationship between the barbiturate effect and the effect of stimulus intensity on RT, allows some insight into the specificity of the barbiturate effect on visual processing. Obviously, a similar reasoning is possible with regard to the relation between the effect of barbiturate and that of the size of the memory set.

Method

Subjects

The subjects were 12 healthy male students with an age range from 19 to 26 years. They were paid Hfl. 60,- a day for participation in the experiment, and a daily bonus of approx. Hfl. 5,- to Hfl. 10,- was awarded on the basis of their performance during the experimental task. One week prior to participating in the experiment, all subjects received a medical examination and were informed about the nature of the drug treatments and the experimental task.

Drug treatment

The drug conditions were an amphetamine derivative (20 mg phentermine HCl), a barbiturate (100 mg pentobarbital sodium) and a placebo. The preparation and administration of the drugs was based on the pharmacokinetic research on barbiturates by Breimer (1974) and amphetamines by Vree (1973). To achieve a relatively constant plasma concentration during the post-treatment experimental sessions, treatments were administered by means of a suppository, and testing was started 1½ hours after treatment and finished

4½ hours later. Allocation of the drug treatment was "double blind" in the sense that both the subjects and the experimenter did not know which drug would be administered.

Experimental task apparatus

The subject was seated at a sloping desk in a sound-attenuating cubicle with dim ceiling illumination. Two response buttons were mounted next to each other on a sloping desk with a distance of 8 cm in between. The subject was instructed to press the right-hand button with his right-hand index finger to indicate that a stimulus belonged to the positive set, and to press the left hand button with his left-hand index finger to indicate that a stimulus belonged to the negative set.

A slide projector was positioned outside the cubicle to project the reaction stimuli onto a screen positioned 1.80 m in front of the subject. The reaction stimuli consisted of the consonants B, D, F, G, H, K, N, R, S, V, X and Z and the digits 2, 3, 4, 5, 6, 7, 8, and 9. In the varied mapping condition both positive and negative stimuli were taken only from the set of 12 consonants. In the consistent mapping condition the positive stimuli were also consonants but the negative stimuli were always digits. The exposure duration of the slides was controlled with a mechanical shutter. Each reaction stimulus had a duration of 200 msec and was preceded by a visual warning stimulus which consisted of a small lamp positioned behind the projection screen in the same spot as the reaction stimulus. The warning stimulus was only visible through the projection screen when turned on. Its duration was 300 msec and its onset preceded the onset of the reaction stimulus by 1000 msec. The cycle duration per trial (between the consecutive onsets of two reaction stimuli) was 5 sec. The background luminance of the projection screen was 0.7 cd/m^2 and the luminance of the warning stimulus was 50 cd/m^2. The luminance of the reaction stimulus was varied by means of a N.D. filter; its luminance was 25.6 cd/m^2 for the high luminance condition and 3.9 cd/m^2 for the low luminance condition.

A PDP 11-03 computer with an internal clock was used to automate the presentation of stimuli and the registration of reaction times.

Design and procedure

For each subject, the programme consisted of a medical examination including blood and urine tests, one training day and three experimental days with one week in between days. On the training day, subjects carried out

the same experimental programme as during experimental days with the exception that they regularly received feedback about their reaction times and error rates. They were instructed that responses should be made as fast as possible but that error rates should be kept to a minimum. They were also told that at the end of the experiment a bonus would be awarded on the basis of their performance. During each experimental day, two subjects were run alternately for four sessions of 35 minutes each. While one subject was resting, the other subject was carrying out the experimental tasks in the cubicle. Drug administration occurred at 9.00 a.m. for half the subjects, while for the other half it occurred at 9.35 a.m.

The design was completely within-subjects. Drug treatment was varied between experimental days and the order of treatments was counterbalanced in the manner of a Latin square. Mapping and luminance were varied between sessions with the order of mapping conditions counterbalanced within each order of drug treatments and the order of luminance conditions counterbalanced within each order of mapping conditions. Each session consisted of 12 series of 22 trials each. Memory set size was varied between series; there were three sizes of memory set, i.e., 1, 2 and 4. Thus, for each of the three memory set sizes there were four series, and the letters defined as the positive set were varied between the four series for each memory size set. Table I summarizes the positive set frequencies of each letter for these twelve series. For each series there was an equal number of positive and negative trials during each series, and the trials in each set were equally distributed among the appropriate stimuli. In this manner, each letter appears an equal number of times in the positive set when trials are summed across series. The sequence of positive trials during each series and the sequence of series during a session were determined randomly and anew for each session. In between the different series within one session there was no rest period or communication with the experimenter. Subjects were instructed by means of slides that a new series would be started and which letters would serve as positive set stimuli. To recapitulate: during varied mapping a letter could belong to the positive set in one series and to the negative set in another series, whilst during consistent mapping a letter could only belong to the positive set.

Table I. Frequency (in percentages) of positive set stimuli for each series (see text).

			LETTERS										
Series	Set size	F	G	Z	S	D	V	H	R	N	B	X	K
1	1	50											
2	1		50										
3	1			50									
4	1				50								
5	2					25	25						
6	2							25	25				
7	2									25	25		
8	2											25	25
9	4					12.5	12.5	12.5	12.5				
10	4									12.5	12.5	12.5	12.5
11	4							12.5	12.5	12.5	12.5		
12	4					12.5	12.5					12.5	12.5

Results

Reaction times

The mean correct RT's are pictured in Fig. 1. The data for positive and negative trials were pooled for presentation in this graph. Reaction times were significantly longer for negative than for positive trials ($F = 55.72$; $df = 1,6$; $p < .01$) and, as is sometimes the case with binary choice tasks (Anderson, 1973; Sternberg, 1975) the increase in RT with set size was greater for trials requiring a positive response than for trials requiring a negative response ($F = 67.19$; $df = 1,12$; $p < .01$). However, the difference between positive and negative trials was consistent across the drug conditions, and there were no significant higher order interactions involving the effect of positive versus negative trials as well as the effect of drugs.

As was expected, there were significant effects of memory set size ($F = 301.13$; $df = 2,12$; $p < .01$), varied versus consistent mapping ($F = 24.96$; $df = 1,24$; $p < .01$) and the interaction between these two variables ($F = 183.86$; $df = 2,48$; $p < .01$); as evident from the figure, the effect

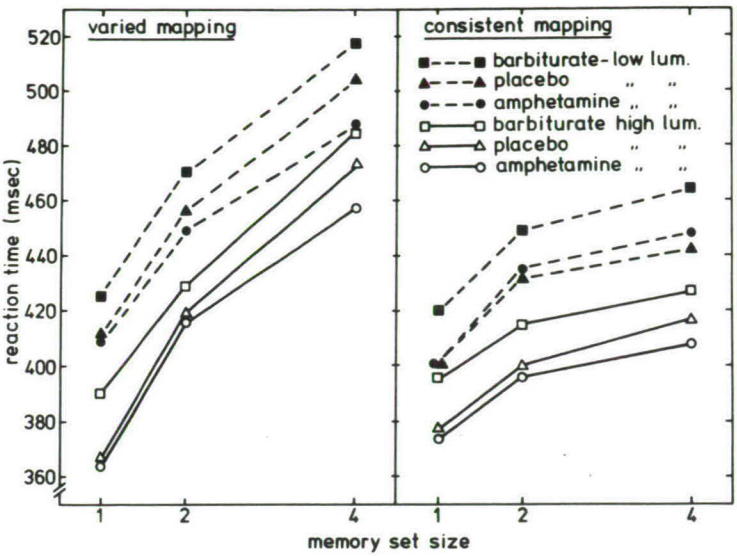

Fig. 1. Reaction time as function of memory set size, varied versus consistent mapping, luminance and drugs.

of memory set size was greater for varied than for consistent mapping. Luminance also had a significant main effect on mean RT ($F = 151$; $df = 1,11$; $p < .01$) and this effect showed no interaction with the effects of memory set size ($F = 1.69$; $df = 2,22$; N.S.) or mapping ($F = 1,01$; $df = 1,11$; N.S.).

Of greater interest from the point of the aims of the experiment are the effects of each of the two drugs and their relationship to the effects of task variables. For this purpose a planned comparisons analysis was carried out to assess the statistical significance of the separate effects of amphetamine and barbiturate as compared to placebo. There was no significant main effect of amphetamine ($F < 1$), and although Fig. 1 suggests that the amphetamine effect was greater for varied than for consistent mapping and increased as a function of memory set size, the analyses did not reach significance for either amphetamine x mapping ($F = 1.33$; $df = 1,22$; N.S.) or amphetamine x memory set size ($F = 2.40$; $df = 2,44$; N.S.). There was also no evidence of interactions of amphetamine with either luminance ($F < 1$; $df = 1,22$; N.S.) or positive versus negative trials ($F < 1$ in both cases).

Regarding the effect of barbiturate there was a significant main ef-

fect ($F = 6.25$; $df = 1,22$; $p < .05$), but there was no evidence of interactions of the barbiturate effect with the effects of memory set size ($F = 1.41$; $df = 2,44$; N.S.), varied versus consistent mapping ($F < 1$; $df = 1,22$; N.S.), luminance ($F < 1$; $df = 1,22$; N.S.) or positive versus negative trials ($F << 1$; $df = 1,22$; N.S.).

Errors

Although no separate analysis of variance was carried out on the error scores, it is appropriate that they should at least be presented to consider whether or not particular effects or lack of effects may be attributable to change in the speed-accuracy trade-off criterion. For this reason, the percentage of errors are presented in Table II.

The mean percentage of errors was below 3% and there was no marked difference between the three drug conditions, although the percentages for placebo were slightly lower than for amphetamine or barbiturate. Regarding the effects of task variables, it does not appear that either luminance or varied versus consistent mapping had any effect; but there was an increase in errors as a function of set size, and this increase was greater for the negative than for the positive trials. This suggests that differences in the speed-accuracy trade-off may have counteracted the effect of set size on RT, and that this counteracting effect was greater for the negative than for the positive trials. This is consistent with the observation that the increase in RT as a function of set size was non-linear (see Fig. 1), and that (as mentioned before) this increase was less for negative than for positive trials.

Discussion

From the point of view of the aims of the experiment, the main feature of these data is that neither of the two drugs showed a significant interaction with any of the four task variables.

Thus, regarding the relationship between the effect of barbiturates and the effect of memory set size, the data support the previous finding of additivity by Mohs, Tinklenberg, Roth and Kopell (1977), which suggested that barbiturates do not affect the memory comparison stage. The finding that the barbiturate effect was additive to the effect of mapping is also consistent with this conclusion.

Table II. Mean percentages of errors for each experimental condition.

MEMORY SET SIZE	POS./ NEG.	VARIED MAPPING						CONSISTENT MAPPING						
		high lum.			low lum.			high lum.			low lum.			
		amph.	plac.	barb.	amph.	plac.	barb.	amph.	plac.	barb.	amph.	plac.	barb.	$\bar{X}$
1	yes	1.7	1.3	2.3	1.1	2.3	1.7	2.1	2.0	2.7	1.9	1.3	2.0	1.9
	no	1.1	1.1	2.7	1.7	.7	1.3	1.5	2.3	2.1	1.9	2.0	1.7	2.1
2	yes	2.0	2.4	2.7	2.9	1.6	2.3	2.3	2.4	1.9	2.1	1.9	2.8	2.3
	no	4.6	2.1	4.3	3.8	4.6	4.0	3.5	3.6	4.7	3.4	3.2	3.4	3.8
4	yes	2.5	3.1	2.0	2.7	1.9	2.7	5.4	3.0	1.6	4.8	2.1	1.7	2.8
	no	5.4	4.4	5.0	4.4	3.8	5.0	3.9	4.0	4.2	3.8	4.7	6.2	4.6
	$\bar{X}$	2.9	2.4	3.2	2.8	2.5	2.8	3.2	2.9	2.9	3.0	2.5	3.0	2.9

The observed additive relationship between the effects of barbiturate and the effect of visual stimulus intensity should be considered in conjunction with the previously found interaction between the effect of barbiturate and stimulus degradation (Frowein, 1981) and the additive relationship between the effects of visual stimulus intensity and visual stimulus degradation (Sanders, 1980). As argued in the introduction, these findings taken together suggest that visual stimulus intensity and visual stimulus degradation affect separate processing stages, and that barbiturate selectively affects the stage affected by stimulus degradation, but has no effect on the stage affected stimulus intensity.

Amphetamine had no main effect on RT and there was no significant interaction of this drug effect with either memory set size or mapping. Nevertheless, Fig. 1 shows no clear additivity with memory set size, but rather a non-significant trend towards an interaction. Since a conclusion of additive effects implies accepting the null hypothesis, even such a trend should be taken seriously. Thus, from these data alone, it cannot be firmly concluded that amphetamine does not affect the memory comparison stage. On the other hand, Mohs, Tinklenberg, Roth and Kopell (Note 1) found no trace of an interaction between set size and the effect of amphetamine, which seems to tilt the weigth of the evidence more towards concluding that amphetamine has no effect on memory comparison. This conclusion would also be more in line with previous data (Frowein, 1981) which suggested that amphetamine has a selective effect on motor stages, and that prior processing stages are not affected. In addition it should of course be noted that an effect of amphetamine on memory comparison in this task should also have been reflected in a main effect of amphetamine on RT.

Regarding the effects of task variables, the results of this experiment confirm the study by Schneider and Shiffrin (1977) which showed that the effect of memory set size was greater for varied than for consistent mapping. Thus, within the context of the additive factor method and the model proposed by Sternberg (1969), it appears that the manipulation of varied versus consistent mapping affects the memory comparison stage. Also, the finding that the effect of luminance is additive with the effects of stimulus set size as well as mapping, may be considered together with previous findings of additivity between visual stimulus degradation and memory set size (e.g. Sternberg, 1969; Johnson and Briggs, 1973) to provide further support to the conclusion that the processes involved

in memory comparison operate independently of the processes involved in the preceding perceptual stages.

Finally, it may be noted that the relations between the task variables were undisturbed by the manipulations of drug treatment. This is a common finding in this type of study, witness the results of some other studies with barbiturates and amphetamines (e.g. Frowein, 1981) with sleep deprivation (Sanders et al., in press) and with normal versus schizophrenic subjects (Sternberg, 1975). It shows that although a change in the state of organism (brought by drugs or other causes) may affect one or more processing stages, the structural organization of the processing stages remains the same. With regard to the applicability of the additive factor logic as opposed to notions of capacity reallocation as a consequence of stress (e.g. Rabbitt, 1979), this is obviously a relevant observation.

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PAPER 7

EP COMPONENTS, VISUAL PROCESSING STAGES, AND THE EFFECT OF A BARBITURATE*

Summary

In a 2 x 2 x 2 factorial experiment, 10 subjects carried out a visual choice reaction task. In addition to RT measurement, evoked potentials (EPs) were recorded from the central (Cz) and occipital (Oz) derivations. Independent variables were drug treatment (barbiturate versus placebo), visual stimulus intensity and visual stimulus degradation. The reaction time data showed that visual intensity and degradation had additive effects, which indicates that these variables affect independent stages, i.e. stimulus preprocessing and stimulus encoding. The effect of a barbiturate on RT was additive with intensity but appeared to interact with degradation. This suggests a selective effect of that drug on the encoding stage. EP components also showed selective effects of intensity, degradation and drug treatment. It was suggested that these components may be related to stages in the reaction process.

* Submitted to Biological Psychology with A.W.K. Gaillard and C.A. Varey as second and third authors

INTRODUCTION

Research on evoked brain potentials (EPs) is becoming an area of increasing importance for the study of human information processing (e.g. Donchin et al., 1978; Hillyard et al., 1978; Näätänen and Michie, 1979). This research has generally focused on the effects of certain task variables on components of the EP.

Many of the studies used selective reaction tasks which fits in with a tradition within EP research to try and establish links between brain potentials and processes of attention. For instance, Ritter et al. (1979) used such a task and manipulated the discriminability between target and non-target stimuli. They found the latency of both N_2 and P_3 were affected by discriminability. Since N_2 is modality-specific and P_3 not (see Simson et al., 1977) and because N_2 occurs earlier, it was inferred that N_2 reflects the detection of the target event and that P_3 reflects some other functional activity. A recent study by Lawson and Gaillard (1981) is consistent with this inference. They manipulated auditory discriminability by manipulating the number of phonetic cues to distinguish between targets and also found that N_2 was particularly sensitive to the number of phonetic cues.

Similar sort of inferences may be arrived at by investigating EP components within the context of the study of mental chronometry. This approach which seeks to identify and characterize the structural components of information processing is well-established as one of the major concerns of reaction time research (e.g. Kantowitz, 1974; Posner, 1978; Lachman et al., 1979). An important instrument in this reaction time research is provided by the additive factor method (AFM), introduced by Sternberg (1969). The basic idea of the AFM is that the reaction process consists of a series of independent processing stages, which can be identified by investigating the relationship between different task variables in their respective effects on RT. According to the rationale of the AFM, it is plausible to infer that different task variables affect independent processing stages if their respective effects on RT are additive, while on interaction indicates that they affect the same processing stage. For instance, it has been consistently shown that the effect of visual stimulus degradation (making a pattern more difficult to recognize) is additive with the effect of S-R compatibility (Sternberg, 1969; Shwartz et al., 1977; Sanders, 1980a).

Thus, assuming that visual stimulus degradation increases the duration of stimulus encoding and that variation of S-R compatibility affects response selection, it may be inferred that stimulus encoding and response selection constitute independent processing stages.

Relating this to EP research it may be possible to establish relationships between EP components and stages of information processing. For instance, a recent experiment by McCarthy and Donchin (1980) studied the functional significance of P_3 within the context of an additive factor experiment. They varied stimulus degradation and S-R compatibility and found that the latency of P_3 was affected by degradation but not by compatibility. This suggests that P_3 latency is sensitive to the duration of the encoding stage and not to the duration of the response selection stage. However, it should be added of course that P_3 may not be the only component associated with encoding. As suggested by the experiments cited earlier, it may be that other earlier components such as N_2 may show an even greater sensitivity to stimulus degradation.

The present study constitutes an additive factor experiment to investigate the effects of visual stimulus intensity, stimulus degradation and a depressant drug on these early EP components as well as RT. It follows on from previous additive factor experiments in which only RT was measured. In these early experiments the AFM was used not only to identify processing stages, but also to investigate the effects of certain drugs and other stresses on these processing stages. With respect to the latter, the rationale of the AFM was applied to the relationship between task variables and drugs in their respective effects on RT. If the effects of a drug on RT interacts with the effects of a certain task variable, it may be inferred that they affect a common processing stage, whereas additivity would suggest that the drug does not influence the processing stage affected by the task variable.

In a previous experiment (Frowein, 1981) it was found that barbiturate increased RT, and this effect showed a small but significant interaction with the effect of visual stimulus degradation, but was additive with the effect of S-R compatibility on RT. Thus, it was concluded that barbiturates affected the same processing stage as stimulus degradation (i.e. encoding), but the stage affected by S-R compatibility was not affected by barbiturate. This conclusion was also consistent with an independently carried-out study by Williams et al. (1981) who also found an interaction be-

tween the effects of a barbiturate and stimulus degradation on RT. In a subsequent experiment by Frowein and Sanders (1981), the effect of barbiturate was jointly investigated with the effect of visual stimulus intensity, and it was found that these effects were additive. To account for this, it was suggested that visual intensity may not affect the stimulus encoding stage but a prior stimulus preprocessing stage. Thus, if barbiturate has a selective effect on encoding and not on stimulus preprocessing, its effect on RT should be additive with the effect of stimulus intensity.

The aim of the present experiment is, firstly, to confirm that stimulus preprocessing and stimulus encoding represent independent processing stages, and that barbiturate effects encoding and not preprocessing, and secondly, the experiment attempts to find EP-correlates of stimulus preprocessing and stimulus encoding, and selective effects of the barbiturate on these EP-correlates.

METHOD

Subjects

The subjects were ten healthy male students from the University of Utrecht with an age range from 19 to 26 years. One week before participating in the experiment, all subjects received a medical examination and were informed about the nature of the drug treatment and the experimental task. They were paid Hlf. 75,- a day for participating in the experiment, and an extra bonus of approx. Hfl. 5,- to Hfl. 10,- a day was awarded on the basis of their performance during the experimental task.

Drug treatment

The treatment conditions consisted of a barbiturate (100 mg pentobarbital sodium) and a placebo. Each subject received the two treatment conditions at weekly intervals. The preparation and administration of the drugs was based on the pharmaco-kinetic research on barbiturates by Breimer (1974). Testing was started 1,5 hours after treatment administration and finished 4 hours later to achieve a relatively constant plasma concentration during the test period. Treatments were self-administered by means of a suppository and allocation was "double-blind" in the sense that neither

the subjects nor the experimenter knew on which days the different treatments would be administered.

Experimental task and apparatus

The task was a visual four-choice reaction task. The subject was seated at a sloping desk in a sound-attenuating cubicle with moderately dim ceiling illumination. A slide projector was positioned outside the cubicle to project the reaction stimuli through a peephole onto a projection screen inside the cubicle. The subject was seated 1.20 m in front of the projection screen and the reaction stimuli were projected at a visual angle of

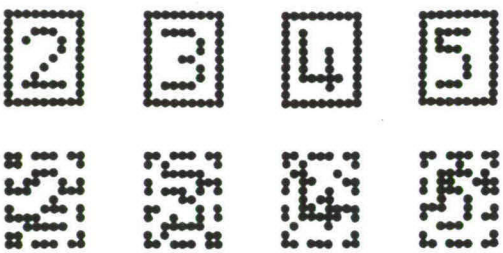

Fig. 1. Undegraded and degraded patterns used as stimuli.

9 degrees. Fig. 1 pictures the reaction stimuli which consisted of the digits 2, 3, 4 and 5. The undegraded digits in the upper row were surrounded by an unbroken frame of dots; whilst in the degraded condition a number of dots were taken from the frame to be positioned at random around the digit. To prevent subjects from learning to respond to the degradation patterns instead of the digits, there were four patterns for each degraded digit. For each of the four digits, one of the alternative degradation patterns is pictured in Fig. 1. For each trial the digit was preceded by a warning signal consisting of a small lamp, positioned behind the projection screen so that it was only visible when turned on. The duration of both the warning signal and the digit was 200 msec, and the onset-onset interval between these two stimuli was 1000 msec. The inter-trial interval between the offset of the reaction stimulus and the onset of the next warning signal was always 50 cd/m^2 as measured in front of the projection screen, while the luminance of the reaction stimuli was varied by means of a neutral density

filter positioned in front of the projector lens. The luminance of the digits was 3.9 cd/m^2 in the low luminance condition and 25.6 cd/m^2 in the high luminance condition, and the background luminance of the projection screen was .06 cd/m^2. An arrangement of four push buttons was mounted on the sloping desk, so that they could be conveniently pressed with (from left to right) the left middle finger, the left index finger, the right index finger and the right middle finger. The four buttons from left to right correspond to the digits 2, 3, 4 and 5. The measurement and registration of the reaction times and the presentation of the stimuli was automated with the aid of a PDP-11-03 computer with an internal clock. Prior to the experiment, the subjects were instructed to respond as fast as possible while keeping errors to a minimum. They were told that, at the end of the experiment, a bonus would be awarded on the basis of their performance, and that they should make good use of the warning stimulus to improve their timing and motor preparation.

Design and Procedure

Drug treatment (barbiturate versus placebo), visual stimulus degradation and luminance were varied in a within-subjects design with two levels for each variable. For each subject, the program consisted of one training day and two experimental days with a one-week interval between days. On training days he regularly received trial-by-trial feedback about his reaction times and errors, while there was no feedback about his performance on the experimental days. In other respects the program of experimental tasks was the same for training and experimental days. During each day, two subjects were run alternately for four sessions which lasted 30 minutes and contained 360 trials each. While one subject was carrying out the reaction task in the experimental cubicle, the other subject was seated in a comfortable chair during his rest-period. Drug treatment was varied between experimental days, and the order of treatment was counterbalanced between subjects. The four task conditions, representing the combination of two levels of stimulus degradation and two levels of luminance were varied between the four experimental sessions, and the sequence of these conditions was varied randomly between subjects. Thus a separate random sequence of task conditions was determined for each subjects and this sequence was maintained during both the training and the experimental days.

EEG-recordings and analysis

During both experimental weeks, the EEG was recorded using chlorided silver-silver disk electrodes at the vertex (Cz) and occipital (Oz) positions. Electrodes on the earlobes were linked to provide a reference and an electrode just above the bridge of the nose served as ground. Vertical eye movements were recorded from above and below the right eye. After AC amplification (time constant 6 sec) the EEG and EOG signals were recorded on magnetic tape (Philips Analog 14).

The signals were analyzed using a PDP-8 computer. For each trial samples were digitized at a rate of 500 per sec, starting 50 msec before the onset of the stimulus and ending 800 msec later. The evoked potentials were then averaged over trials for each site separately, per subject per condition. The average of the 25 samples in the 50 msec period preceding stimulus onset was taken as the baseline amplitude. Latencies and amplitudes of the N_1, P_2, N_2, P_3 and N_3 were measured. These components were denoted as follows: N_1 was the most negative deflection between 80 and 200 msec; P_2 was the most positive deflection between 150 and 270 msec; and N_2 was the most negative deflection between 210 and 350 msec. EEG peak measures were rejected if the EOG was $\pm$ 50 μV greater than the pre-stimulus baseline. This was frequently the case for latencies longer than 350 msec, which meant that the P_3 and N_3 measures had to be excluded from the analysis. In addition, the EEG of one subject were completely rejected, due to excessive EOG artifacts.

RESULTS

Reaction times and errors

The mean correct RT and the percentage of errors was computed for each individual session and used as the basic data for the analyses of variance. The percentages of errors are summarized in Table I. The errors were more frequent for degraded than for undegraded digits ($F = 14.93$; $df = 1,8$; $p < .01$), but there was no significant effect on the percentage of errors of luminance ($F < 1$) or drug treatment ($F = 2.01$; $df = 1,8$; N.S.). Also none of the interactions approached significance.

Of greater interest are the effects of these variables on the mean cor-

Table I. Percentage of errors for each experimental condition.

	Placebo	Barbiturate
Undegraded / High luminance	2.8	2.8
Undegraded / Low luminance	2.7	2.9
Degraded / High luminance	4.1	4.7
Degraded / Low luminance	4.2	5.1

rect RT. These data are pictured in Fig. 2. This shows a large effect of visual stimulus degradation ($F = 90.86$; $df = 1,8$; $p < .01$) and a smaller but quite consistent effect of luminance ($F = 26.97$; $df = 1,8$; $p < .01$). Furthermore, the relationship between these two variables appears to be additive ($F < 1$). The main effect of drug treatment on the mean RT was also significant ($F = 10.04$; $df = 1,8$; $p < .05$), and this effect appears to be additive with the effects of luminance ($F < 1$). Regarding the relationship between the barbiturate effect and the effect of visual stimulus degradation, the figure shows a greater effect of barbiturate in the degraded

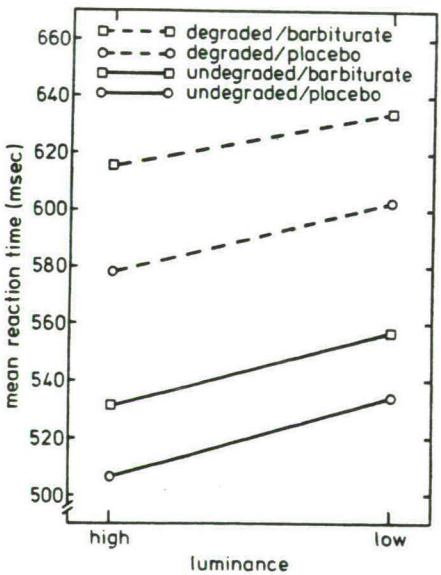

Fig. 2. Mean reaction time as a function of stimulus intensity, stimulus degradation and drug treatment (barbiturate versus placebo).

than in the undegraded condition, but this interaction was not significant ($F = 1.99$; df = 1,8; N.S.). Also there was no evidence of a second-order interaction between the effect of barbiturate, degradation and luminance ($F < 1$).

Evoked potentials (EPs)

Analyses of variance were carried out on the latency and amplitude of each of the three components, for each derivation. Since none of the interactions between intensity, stimulus degradation and drug treatment were significant, only the main effects are presented in Table II and III.

Table II. The latencies (in msec) for the main effects, averaged across subjects and the other factors. Also the differences (dif.), F-values (df 1,43) and p-values are given. Difference values which were not in the expected direction received a minus sigm. P-values larger than 0.05 are regarded as insignificant.

	Oz: N_1	P_2	N_2	Cz: N_1	P_2	N_2
Intensity						
high	116	216	206	106	179	241
low	161	241	300	123	205	269
dif.	45	25	14	17	26	28
F	172.6	64.8	22.7	66.1	83.2	107.4
p	< .01	< .01	< .01	< .01	< .01	< .01
Degradation						
undeg.	137	227	292	114	188	251
deg.	139	230	295	116	195	261
dif.	2	3	3	2	7	10
F	0.3	1.2	1.4	0.4	6.0	14.9
p	N.S.	N.S.	N.S.	N.S.	.05	< .01
Treatment						
placebo	135	228	292	115	194	256
barb.	141	229	295	115	189	255
dif.	6	1	3	0	-5	-1
F	2.8	0.6	0.2	0.0	3.2	0.2
p	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Table III. The amplitudes (in V) for the three main effects (see also Table II).

	Oz: N_1	P_2	N_2	Cz: N_1	PP_2	N_2
Intensity						
high	-6.7	12.0	5.3	-3.1	7.6	-0.3
low	-3.0	8.5	3.3	-3.4	7.2	-0.1
dif.	3.7	3.5	2.0	-0.3	-0.4	-0.2
F	57.1	48.6	14.3	0.9	0.7	0.2
p	< .01	< .01	< .01	N.S.	N.S.	N.S.
Degradation						
undeg.	-5.3	11.4	5.0	-3.2	8.1	0.6
deg.	-4.4	9.1	3.6	-3.4	6.7	-1.0
dif.	0.9	2.3	1.4	-0.2	1.4	1.6
F	3.1	21.1	6.9	0.3	9.4	14.1
p	N.S.	< .01	< .01	N.S.	< .01	< .01
Treatment						
placebo	-5.2	10.6	4.7	-3.7	8.3	0.1
barb.	-4.6	10.0	3.9	-2.9	6.4	-0.4
dif.	0.6	0.6	0.8	0.8	1.9	0.7
F	1.4	1.4	2.1	7.2	16.3	1.1
p	N.S.	N.S.	N.S.	< .01	< .01	N.S.

There were highly significant effects of visual intensity on the latency of the three components in the Cz- as well as the Oz-derivation; the largest effect was on the N_1 component in the Oz-derivation. Intensity also had a clearly significant effect on the amplitude of all three components of the Oz-derivation (again with the largest effect in N_1), but there was no evidence of an intensity effect on amplitude in the Cz-derivation.

Degradation had no effect on the peak latencies in the Oz-derivation, and although there were significant effects on P_2-latency and N_2-latency in the Cz-derivation, these effects were quite small. The effects of degradation on amplitudes were more prominent. There were clear effects on P_2-amplitude and N_2-amplitude in both derivations, but there was no effect

of degradation on N_1-amplitude in either Oz or Cz.

Drug treatment did not affect any of the component latencies in either Oz or Cz, but there was a prominent drug effect on P_2-amplitude in the Cz-derivation. Table III also suggests smaller effects of drug treatment on amplitudes of the other components, but the only other significant effect was on N_1-amplitude in Cz.

The effects of degradation and drug treatment on the evoked potential are further illustrated by the waveforms (averaged across subjects) presented in Fig. 3. It can be seen that drug treatment and degradation have similar effects in the Cz-derivation, particularly on P_2; but they have different effects on Oz. Drug treatment had no noticeable effect on the com-

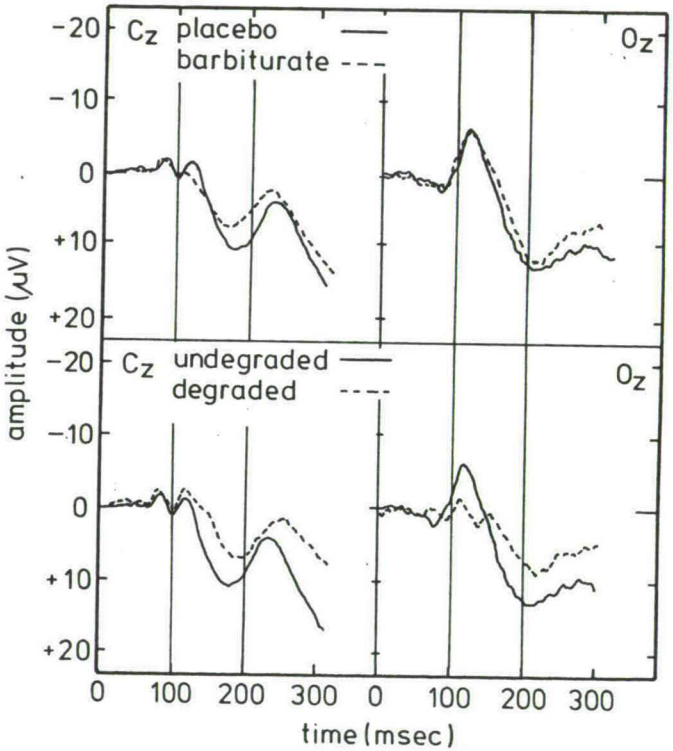

Fig. 3. EPs (averaged across subjects) from the Cz and the Oz derivation. Top panel: EPs as a function of treatment under the high intensity and undegraded condition. Bottom panel: EPs as a function of degradation under the high intensity and placebo condition.

ponents of Oz, whereas there were clear effects of degradation in Oz where both the P_2 and the N_2 components were significantly reduced. Fig. 7 also indicated an effect of degradation on N_1, but this did not quite reach significance ($p < .10$), because it was only present in a few subjects.

DISCUSSION

As predicted the effects of visual stimulus intensity and degradation on RT showed additive contributions to RT. This is also consistent with similar data reported by Sanders (1980b). In accordance with additive factor analysis it can thus be inferred that visual stimulus intensity and degradation affect two independent processing stages, and these may be denoted as stimulus preprocessing and encoding. Stimulus preprocessing would presumably be the first processing stage and it may be of purely sensory nature. Encoding, on the other hand, may best be regarded as the pattern recognition input involving a linking up between sensory input and memory.

The observed effects of visual stimulus intensity and degradation on the EP components can be interpreted as consistent with these postulated stages. The effect of visual intensity on N_1-latency was of similar magnitude as its effect on RT, which indicates that the intensity effect on RT may be explained in terms of the early processing preceding the N_1-peak. Also the intensity effect on N_1-latency was most prominent at Oz and its effect on amplitude occurred only at that derivation. This suggests that this effect is modality-specific. It may thus be hypothesized that N_1 reflects stimulus preprocessing. This is also consistent with the recent literature reviews which seem to agree that N_1 reflects an early phase of stimulus processing and is affected by the physical characteristics of stimulus presentation (Donchin et al., 1978; Hillyard et al., 1978; Näätänen and Michie, 1979).

Degradation, contrary to stimulus intensity, did not have a significant effect on N_1. Its first significant effect on EP occurred at P_2 where it had a marked effect on amplitude, and a similar effect on N_2-amplitude was observed. However, the effects of degradation on the latencies of P_2 and N_2 were relatively small and in no way comparable to the degradation effect on RT. Thus, if the degradation effect on RT represents an effect on the duration of encoding and this effect is reflected in P_2 and N_2, it must

be concluded that encoding was not yet completed at the N_2-peak. In this respect, the present data differ from the previously mentioned results by Ritter et al. (1979) who used an auditory task. However, it is not implausible that the encoding of visual stimuli (such as used in the present study) may be reflected by a cluster of EP components. Thus, it may be that encoding begins at P_2, carries on during N_2, and it completed sometime after that, possibly at P_3. This would be consistent with McCarthy and Donchin (1980), who also used visual stimuli and found that the effect of pattern degradation on RT was reflected in its effect on RT.

With respect to its topographical aspects it is not clear whether the degradation effect is located at Oz or at Cz. In topographical studies, P_2 has a broad distribution around the parietal association cortex (e.g. Simson et al., 1977). Thus, a more definite statement may be made by recording at Pz as well as Oz and Cz.

Regarding the relationship between the barbiturate effect and the effect of the two task variables on RT, the data confirms the previous finding of additivity between the effects of barbiturate and visual stimulus intensity (Frowein and Sanders, 1981), but the interaction between barbiturate-treatment and stimulus degradation was not significant. However, considering that this interaction was significant in two previous studies carried out independently from each other (Frowein, 1981; Williams et al., 1981) and that the present results show an effect in the same direction, it is plausible to infer that barbiturate affects the encoding stage.

The EP-data are partially consistent with this inference. The effects of barbiturate and degradation were similar in their effect on P_2-amplitude at the Cz-derivation. On the other hand, they were clearly different in that degradation showed effects at Oz as well as at Cz, whereas barbiturate had no effect at Oz. This suggests that the barbiturate effect (unlike the degradation effect) is not modality-specific. This is also evident when comparing the present results with a recent study by Hink et al. (1978). Using an auditory task and a selective attention paradigm, they also found a barbiturate effect on the amplitude of N_1 and P_2 at the Cz-derivation. In addition, a recent experiment by Frowein et al. (in preparation) with auditory as well as visual reaction tasks, also showed similar barbiturate effects in both types of tasks.

With regard to the latencies of EP-components, the presently observed barbiturate effects are also consistent with the study by Hink et al.

(1978). None of the registered latencies were affected by the barbiturate. As with degradation, the effect of barbiturate on RT was not reflected by an effect on the latencies of either P_2 or N_2. Thus, the barbiturate effect on P_2-amplitude may be only a partial reflection of its effect on encoding. If, as suggested before, P_2 (in a visual task) reflects only the beginning of encoding, and a later component such as P_3 represents its completion, a barbiturate effect on encoding should also be reflected in an effect on the latency of this later component.

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SUMMARY

The literature on the performance effects of stimulant and depressant drugs suggests that these effects are often task-specific. This indicates selective effects of these drugs on the processes which determine performance. The additive factor method which has been used to identify information processing stages, can also be used to identify the selective effects of a 'stress' such as a drug. This involves research into the relationship between the effects of a stress and the effects of certain task variables in their respective effects on reaction time.

This thesis applies the additive factor method to investigate the effects of an amphetamine derivative (phentermine) and a barbiturate (pentobarbital) in accordance with this strategy. It consists of two parts: a review part (Part I) and a series of research papers (Part II). Chapter 1 reviews the research strategy. Chapter 2 presents a model of the information-processing stages which make up the reaction process. Chapter 3 reviews the literature on the biochemical, psychophysiological and behavioural effects of amphetamine and barbiturate; and some suggestions are made about their possible effects on different information processing functions. Chapter 4 reviews the main experimental findings. Amphetamine was inferred to affect the motor output stages, whereas the locus of the barbiturate effect was found in the stimulus encoding stage. Sleep deprivation (which was also investigated in one of the experiments) had effects on motor output stages, opposite to those of amphetamine. Chapter 5 relates these findings to a number of theories of arousal and attention. It concludes that drug effects may be found on the level of attentional control as well as on the level of automatic processing, and that on either of these two levels these effects are likely to be selective rather than general.

SAMENVATTING

De invloed van stimulerende en sederende psychofarmaca op de prestatie, wordt mede bepaald door de taak die de proefpersoon moet uitvoeren. Dit wijst erop dat deze stoffen een selectieve invloed uitoefenen op de processen die de prestatie bepalen. De additieve factoren methode, om stadia in de informatieverwerking te identificeren, kan ook gebruikt worden om dergelijke selectieve stressor effecten nader te identificeren. Dit houdt in het onderzoeken van de relatie tussen de invloed van een stressor (zoals een psychofarmacon) en van bepaalde taakvariabelen op de reactietijd.

Dit proefschrift gebruikt deze strategie om de invloed te onderzoeken van een amfetamine derivaat en een barbituraat. Het bestaat uit twee delen: een overzicht (Deel I) en een verzameling onderzoeksverslagen (Deel II). Hoofdstuk 1 van het overzicht bespreekt de onderzoekstrategie. Hoofdstuk 2 geeft een analyse van de informatieverwerkingsstadia in het reactieproces. Hoofdstuk 3 geeft een overzicht van de biochemische, psychophysiologische en gedrags effecten van amfetaminen en barbituraten. Op basis hiervan worden enkele suggesties gedaan m.b.t. de te verwachten effecten van deze psychofarmaca op de informatieverwerking in de mens. Hoofdstuk 4 geeft een overzicht van de belangrijkste bevindingen. Amfetamine blijkt de motorische stadia te beïnvloeden, terwijl het barbituraat aangrijpt op het perceptuele codeerstadium. Bovendien werd aangetoond dat slaap deprivatie (ook onderzocht in één van de experimenten) evenals amfetamine de motorische stadia beïnvloedt. Hoofdstuk 5 bespreekt enkele theorieën over aandacht en arousal in het licht van deze bevindingen. Dit leidt tot de algemene conclusie dat stressoren (zoals farmaca) zowel automatische als aandachtsvereisende verwerkingsprocessen kunnen beïnvloeen , en dat op elk van deze twee niveau's selectieve invloeden verwacht kunnen worden.

VII

De meeste psychologische theorieën lijken op "old soldiers; they never die, they just fade away ...".

VIII

De grote vraag naar maatschappelijk relevant onderzoek heeft vaak tot gevolg dat te weinig aandacht wordt besteed aan wetenschappelijke haalbaarheid. In de sociale wetenschappen heeft dit geleid tot een wildgroei van nieuwe disciplines en sub-disciplines, die wel veel nieuwe woorden maar weinig nieuwe kennis bijdragen.

IX

Het wetenschapsbeleid in Nederland is een regentenbeleid.

X

Problemen zijn in principe altijd oplosbaar, dilemma's nooit.

Stellingen bij: "Selective drug effects on information processing"

H.W. Frowein

Tilburg, 4 september 1981

S T E L L I N G E N

I

Vooruitgang in de wetenschap is in eerste instantie een kwestie van het stellen van de juiste vragen.

II

Theoretisch onderzoek naar de invloed van een stressor op de prestatie, dient erop gericht te zijn welke van de verschillende processen, betrokken bij het uitvoeren van een taak, beïnvloed worden.

III

Het unidimensionele arousal model en de Yerkes-Dodson wet danken hun populariteit eerder aan hun eenvoud en subjectieve invoelbaarheid dan aan wetenschappelijke evidentie.

IV

'Effort' moet eerder gezocht worden bij beslissen, probleem oplossen en motoriek dan bij perceptie. Denken en doen kosten meer moeite dan horen en zien.

V

Psychologische modellen van informatieverwerking bij de mens kunnen aanzienlijk worden verrijkt door onderzoek naar de relatie tussen psychophysiologische en gedragsvariabelen.

VI

Voor efficient typen zijn cognitieve aspecten van groter belang dan de structuur van het toetsenbord.